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A SECTION OF THE VIRGINIA DEMONSTRATION ROAD

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THE VIRGINIA DEMONSTRATION ROAD

A DESCRIPTION OF THE PROJECT AND DATA RECORDED DURING CONSTRUCTION

Reported by A. C. BENKELMAN, formerly Associate Research Specialist, Division of Tests, U. S. Bureau of Public Roads

THE Virginia demonstration road was constructed to determine the influence of a number of materials and methods of construction upon the behavior and life of concrete pavements. It consists of 60 sections varying in length from 100 feet to 1 mile, and with an aggregate length of 12 miles. The work has been done as a Federal-aid project by the Virginia State Highway Commission under the direction of Henry G. Shirley, chairman, and C. S. Mullen, chief engineer, and is known as project 336, sections C, D, and E.

The location is on the main route from Washington, D. C., to the Valley of Virginia between Fairfax and Warrenton and crosses the famous Bull Run battlefield. Previous reports have been made concerning the construction of this project.[1]

OBJECT OF THE INVESTIGATION DISCUSSED

As indicated by the number of sections constructed, the experiment embraces a large number of variables. The slab cross section was varied in several instances, but study of this factor was not a primary object, since the efficiency of the standard Virginia cross section (8 inches thick at the edge, 6 inches thick at the center, and 18 feet wide) was not in question in this investigation. It was desired primarily to learn the relative benefits or adverse effects of different aggregates, different admixtures, different types and weights of reinforcement, different methods of finishing, various methods of curing, and different methods now used for the control of transverse and longitudinal cracking.

In order to properly evaluate these variables, there was included also a study of the influence of such factors as subgrade conditions, climatic conditions during construction, the consistency and water content of the concrete mixes, and the strength of the concrete as indicated by tests on cylinders, cores, and beams.

GENERAL FEATURES OF PROJECT DESCRIBED

The new road in general follows the horizontal alignment of the old Warrenton Turnpike. The vertical alignment was modified to such an extent that in only a very few instances does the new surface rest directly upon the old roadbed. The original road was in existence at the time of the Civil War and perhaps many years prior to that period. It has been improved from time to time and has served as a line of travel to the Valley of Virginia from the east. The earlier improvements involved the construction of a stone base and sand-clay or broken shale surface. The character and thickness of the base depended apparently upon the nature of the subgrade encountered. Large bowlders were used for the sub-base in the clay soils and poorly drained areas and shale fragments were used in other locations.

The new road was built with State equipment and convict labor. A superintendent, acting under the direction of the resident and district engineers of the State highway commission, was in charge of the various construction activities. A field camp was established in the fall of 1925 at the quarry on project 336 C (station 485) and served as the operating base for the construction of projects 336 C and D. The camp was moved during the summer of 1927 to a new quarry site on project 336 E (station 900) and construction of this project carried on from this point.

A TYPICAL SECTION OF THE ROAD

Materials were proportioned from stock piles at the respective operating bases and were transported to the mixer in trucks. The concrete was mixed with a 4-bag 21-E Koehring paver equipped with a batch meter and water-control mechanism. The water was pumped to the paver from near-by streams and was generally clear, free from impurities, and gave a satisfactory strength ratio in all tests.

The maximum grade of the new pavement is 7 per cent. There are only a few changes in alignment in the entire road and these are so slight that the pavement is not superelevated.

The Virginia specifications require a 6-foot shoulder on fills with an embankment slope of 1½ to 1 and a 7-foot shoulder in cuts with a slope of 1 to 1. The shoulders are composed of the natural soil with a slope of one-half inch to the foot.

MANY VARIABLE FEATURES INCLUDED IN DESIGN

Table 1 shows the character of the various sections, listing the general and special features, the length and location by stations, and date of construction. The major differences in the details of the section are as follows:

1. Three cross sections, 8-6-8, 9-7-9, and 7-inch uniform.
2. Three methods of finishing—hand, Vibrolithic, and machine (Ord and Lakewood).
3. Five admixtures—hydrated lime (5 and 8 per cent), Celite (3 per cent), diatomaceous earth (3 and 4 per cent), calcium chloride (2 per cent), and Cal (5 per cent).
4. Five methods of curing—wet earth, calcium chloride, and sodium silicate (surface), calcium chloride and Cal (in the mix).

[1] HOGENTOGLER, C. A. VIRGINIA BUILDING DEMONSTRATION ROAD. Public Roads, vol. 7, No. 6, Aug., 1926.
ALBRIGHT, J. C. VIRGINIA DEMONSTRATION ROAD. Proceedings of Sixth Annual Meeting of the Highway Research Board. Dec. 2, 1926.

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TABLE 1.—*Details of various sections*

Federal-aid project and section No.	Length	Station		Date of construction		Cross section	Finish	Curing	Admixtures	Materials		
		From—	To—	From—	To—					Cement	Fine aggregate	Coarse aggregate
336 C:	Feet											
1	3,935.0	293+00.0	332+35.0	1926 May 6	1926 May 19	8-6-8	Vibrolithic	Wet earth		A	A	Stone A
2	1,358.0	332+35.0	351+10.0	May 19	May 22	8-6-8	do	do		A	A	do
3	527.5	351+10.0	356+37.5	May 24	May 24	8-6-8	Hand	do	5 per cent lime	A	A	do
4	100.0	356+37.5	357+37.5	May 25	May 25	8-6-8	do	do	8 per cent lime	A	A	do
5	762.5	357+37.5	365+00.0	do	May 26	8-6-8	do	do	5 per cent lime	A	A	do
6	3,980.0	365+00.0	404+80.0	do	June 14	8-6-8	do	do		A	A	do
7	1,522.5	404+80.0	420+02.5	June 14	June 18	8-6-8	do	do		A	A	do
8	860.5	420+02.5	428+63.0	June 19	June 22	8-6-8	do	do		A	A	do
9	552.0	428+63.0	434+15.0	June 22	June 23	8-6-8	do	do		A	A	do
10	1,625.0	434+15.0	450+40.0	June 23	June 26	8-6-8	do	do	3 per cent Celite	A	A	do
11	205.0	450+40.0	452+45.0	June 28	June 28	8-6-8	do	do		A	A	do
12	475.0	452+45.0	457+20.0	June 29	June 30	8-6-8	do	do		A	A	do
13	120.0	457+20.0	458+40.0	June 30	do	8-6-8	do	do		A	A	do
14	365.0	458+40.0	462+05.0	do	July 1	8-6-8	do	do		A	A	do
15	87.0	462+05.0	462+92.0	July 1	do	8-6-8	do	do		A	A	do
16	308.0	462+92.0	466+00.0	July 2	July 2	8-6-8	do	do		B	A	do
17	53.0	466+00.0	466+53.0	do	do	8-6-8	do	do		B	A	do
18	77.0	466+53.0	467+30.0	do	do	8-6-8	do	do		B	A	do
19	120.0	467+30.0	468+50.0	do	do	8-6-8	do	do		A	A	do
20	685.0	468+50.0	475+35.0	July 6	July 7	7-inch uniform.	do	do		A	A	do
21	200.0	475+35.0	477+35.0	July 7	do	do	do	do		B	A	do
22	422.5	477+35.0	481+57.5	July 8	July 9	do	do	do		B	A	do
23	625.0	481+57.5	487+82.5	July 9	July 10	8-6-8	do	2 per cent calcium chloride mixed.	2 per cent calcium chloride.	B	A	do
24	737.5	487+82.5	495+20.0	July 12	July 13	8-6-8	do	do	do	A	A	do
25	2,780.0	495+20.0	523+00.0	Apr. 21	Apr. 27	8-6-8	do	Wet earth		A	A	do
336, D:												
26A	123.0	523+00.0	524+23.0	1927 May 27	1927 May 27	8-6-8	Ord	Wet earth	3 per cent Celite	A	B	do
26B	611.0	524+23.0	530+34.0	May 25	do	8-6-8	do	do	4 per cent diatomaceous earth.	A	B	do
26C	491.0	531+77.0	536+68.0	May 23	May 24	8-6-8	do	do	3 per cent diatomaceous earth.	A	B	do
26D	439.0	536+68.0	541+07.0	May 21	May 23	8-6-8	do	do	do	A	B	do
27	1,189.0	541+07.0	552+96.0	May 16	May 20	8-6-8	do	do		A	B	do
28A	522.0	552+96.0	558+18.0	May 12	May 14	8-6-8	do	do		A	B	do
28B	1,002.0	558+18.0	568+20.0	May 7	May 12	8-6-8	do	do		A	B	do
29	1,665.0	568+20.0	584+85.0	May 2	May 7	7-inch uniform.	do	do		A	B	do
30A	247.0	584+85.0	587+32.0	May 3	May 3	8-6-8	do	do		A	B	do
30B	1,170.0	587+32.0	599+02.0	1926 Nov. 13	1926 May 2	8-6-8	do	do		A	B	do
31	105.0	599+02.0	600+07.0	Nov. 8	Nov. 8	8-6-8	Lakewood	Wet burlap, 24 hours only.		High alumina	B	do
32	1,473.0	600+07.0	614+80.0	Nov. 3	Nov. 8	8-6-8	do	Wet earth		A	B	do
33	1,530.0	614+80.0	630+10.0	Oct. 28	Nov. 3	8-6-8	do	do		A	B	do
34	587.0	630+10.0	635+97.0	Oct. 27	Nov. 28	8-6-8	do	2 pounds calcium chloride (surface).		A	B	do
35A	940.0	635+97.0	645+37.0	Oct. 20	Nov. 23	8-6-8	do	2 per cent calcium chloride, mixed.	2 per cent calcium chloride.	A	B	do
35B	977.0	645+37.0	655+14.0	Oct. 15	do	8-6-8	do	do	do	A	B	do
36	1,506.0	655+14.0	670+20.0	Oct. 9	Nov. 15	8-6-8	do	Wet earth		A	B	do
37A	1,490.0	670+20.0	685+10.0	Oct. 4	Nov. 9	8-6-8	do	do		A	B	do
37B	51.0	685+10.0	685+61.0	Sept. 25	Sept. 25	8-6-8	Ord	do		A	B	do
38	1,424.0	685+61.0	699+85.0	Sept. 21	Sept. 24	8-6-8	do	do		A	B	do
39	1,502.0	699+85.0	714+87.0	Sept. 16	Sept. 21	8-6-8	do	do	3 per cent Celite	A	B	do
40	1,513.0	714+87.0	730+00.0	Sept. 11	Sept. 16	8-6-8	do	do		A	B	do
41	1,520.0	730+00.0	745+20.0	Sept. 3	Sept. 11	8-6-8	do	do		A	B	do
42A	633.0	745+20.0	751+53.0	Sept. 1	Sept. 3	9-7-9	Hand	do		A	B	do
42B	837.0	751+53.0	759+90.0	Aug. 28	Aug. 31	9-7-9	Ord	do		A	B	do
43A	880.0	759+90.0	768+70.0	Aug. 13	Aug. 28	8-6-8	do	do		A	B	do
43B	620.0	768+70.0	774+90.0	Aug. 11	Aug. 13	8-6-8	do	do		A	A	do
44	670.0	774+90.0	781+60.0	Aug. 9	Aug. 11	8-6-8	do	do		A and B	A	do
45	1,340.0	781+60.0	795+00.0	Aug. 2	Aug. 9	8-6-8	do	do		A and B	A	do
336, E:												
46A	1,311.0	795+00.0	808+11.0	1927 June 29	1927 July 1	8-6-8	do	do		A	B	Gravel No. 2
46B	1,247.0	808+11.0	820+58.0	July 1	July 6	8-6-8	do	do		A	B	do
47A	1,344.0	820+58.0	834+02.0	July 9	July 14	8-6-8	do	do		A	B	Gravel No. 1
47B	1,190.0	834+02.0	845+92.0	July 14	July 18	8-6-8	do	do		A	B	do
48A	1,408.0	845+92.0	860+00.0	July 20	July 22	8-6-8	do	do		A	B	Stone B
48B	1,333.0	860+00.0	873+33.0	July 23	July 26	8-6-8	do	do		A	B	do
49	927.0	981+29.0	990+56.0	Sept. 3	Sept. 3	8-6-8	do	do		A	B	do
	460.0	996+75.0	1,001+35.0	Sept. 21	Sept. 23	8-6-8	do	do		A	B	do
50	1,579.0	1,001+35.0	1,017+14.0	Aug. 30	Sept. 2	8-6-8	do	Sodium silicate (surface).		A	B	do
51	1,303.0	1,017+14.0	1,030+17.0	Aug. 24	Sept. 27	8-6-8	do	2 per cent calcium chloride, mixed.	2 per cent calcium chloride.	A	B	do
52	1,450.0	1,042+58.0	1,057+08.0	Aug. 11	Sept. 16	8-6-8	do	5 per cent Cal., mixed.	5 per cent Cal.	A	B	do

[1] No correction for bulking of sand.

[2] Corrected for sand bulking.

of Virginia demonstration road

Mix	Reinforcement: Type	Reinforcement: Per 100 square feet	Joints: Transverse: Construction	Joints: Transverse: Expansion	Joints: Longitudinal	Planes of weakness: Transverse	Planes of weakness: Longitudinal	Subgrade treatment: Nature	Subgrade treatment: Location (stations)
		Pounds				*Feet*			
[1] 1:2:4			Noon and night						
[1] 1:2:4			do						
[1] 1:2:4			do						
[1] 1:2:4			do						
[1] 1:2:4			do						
[1] 1:2:4			do						
[1] 1:2:4	Welded fabric, 1 layer.	42	do					2 inches of stone screenings.	412+50 to 420+2.5.
[1] 1:2:4	Welded fabric, 2 layers.	85	do					do	420+2.5 to 428+63.
[1] 1:2½:3½	do	85	do					do	428+63 to 434+15.
[1] 1:2:4			do					do	434+15 to 435+00.
[1] 1:2:4			do						
[1] 1:2:4			do				L. P. W		
[1] 1:2:4			do				do	1 layer of tar paper	Entire section
[1] 1:2:4			do				do	1 inch of stone screenings	461+60 to 462+05.
[1] 1:2:4			do				do	2 layers of tar paper	Entire section.
[1] 1:2:4			do				do		
[1] 1:2:4			do				do	1 layer of Mosinee paper	Do.
[1] 1:2:4			do				do		
[1] 1:2:4			do				do		
[1] 1:2:4			do			40	do	1 inch of stone screenings	468+90 to 471+00 and 473+00 to 475+00.
[1] 1:2:4			do			40	do	do	475+60 to 476+75.
[1] 1:2:4			do			40	L. P. W., doweled.[3]		
[1] 1:2:4			do					2 inches of stone screenings.	485+00 to 485+50.
[1] 1:2:4			do					1 inch of stone screenings	488+00 to 488+40.
[1] 1:2:4			Night						
[2] 1:2:4				½-inch, 40 feet.					
[2] 1:2:4				do					
[2] 1:2:4				do					
[2] 1:2:4						40 and 100			
[2] 1:2:4				½-inch, 60 feet.	Steel center joint, doweled.			1 inch of stone screenings	546+80 to 547+40.
[2] 1:2:4					do	40 and 100			
[2] 1:2:4				½-inch, 40 feet.	do				
[2] 1:2:4				½-inch, 60 feet.			L. P. W		
[2] 1:2:4	Bar mat, 1 layer	50				40 and 100	L. P. W		
[2] 1:2:4	do	50		½-inch, 40 feet.			L. P. W		
[2] 1:2:4				½-inch, night.			L. W. P., doweled.[3]		
[2] 1:2:4	Expanded metal, 1 layer.	42		½-inch, noon and night.		40 and 100	L. P. W	1 inch of stone screenings 2 inches of stone screenings.	604+60 to 606+27. 610+50 to 611+50.
[2] 1:2:4	Welded fabric, 1 layer.	42		do		40 and 100	L. P. W	1 inch of stone screenings	618+75 to 619+50
[2] 1:2:4				do		40 and 100			
[2] 1:2:4						40 and 100		1 inch of stone screenings	640+50 to 641+75
[2] 1:2:4				½-inch, 40 feet.					
[2] 1:2:4	Bar mat, 2 layers	100		½-inch, noon and night.		40 and 100			
[2] 1:2:4	Bar mat, 1 layer	50		do		40 and 100		1 inch of stone screenings 2 inches of stone screenings	678 + 50 to 679 + 50, 683+25 to 684+75. 681+20 to 682+20.
[2] 1:2:4	do	50		do					
[1] 1:3:3½				do		40 and 100			
[2] 1:2:4				do		40 and 100			
[2] 1:2:4	Expanded metal, 1 layer.	42		do		40 and 100			
[2] 1:2:4	Welded fabric, 1 layer.	42		do		40 and 100			
[2] 1:2:4				do		40 and 100			
[2] 1:2:4				do		40 and 100			
[1] 1:1½:3				do		40 and 100			
[1] 1:1½:3				do		40 and 100			
[1] 1:2:4				do		40 and 100		1 inch of stone screenings	779+00 to 781+60.
[1] 1:2:4			Noon and night					1 inch of stone screenings 2 inches of stone screenings.	781+60 to 786+75. 793+25 to 794+25.
[2] 1:2:4				1 inch, noon and night.			L. P. W., doweled.[3]		
[2] 1:2:4				do		30, 40, and 50	do		
[2] 1:2:4				do			do		
[2] 1:2:4				do		30, 40, and 50	do		
[2] 1:2:4				do			do		
[2] 1:2:4				do		30, 40, and 50	do		
[2] 1:2:4				do		40	do		
[2] 1:2:4				do		40	do		
[2] 1:2:4				do		40	do		
[2] 1:2:4				do		40	do		
[2] 1:2:4				do		40	do		

[3] Dowels, ⅝ inch diameter deformed bars, 4 feet long, spaced on 5-foot centers, 3 inches from surface.

5. Materials—three cements (two Portland and lumnite), two sands (different character and grading), two crushed stones (same character and grading, different sources), and two gravels (same character, different grading).

6. Five mixes—1:2:4, 1:2½:3½, 1:3:3½, and 1:1½:3, all without correction for bulking, and a 1:2:4 mix with correction for bulking.

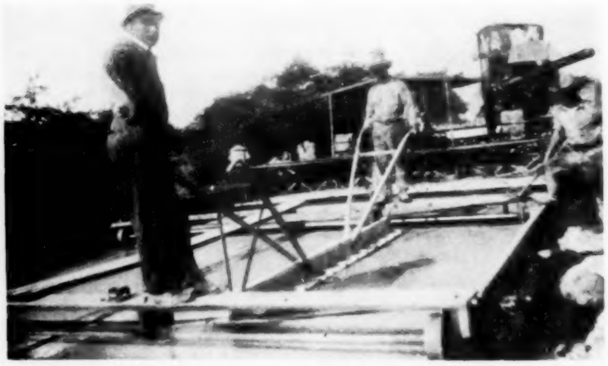
7. Three types of reinforcement—welded fabric (single and double layer) expanded metal (single layer) and bar mat (single and double layer).

8. Joints—transverse (construction and expansion) and longitudinal.

9. Planes of weakness—transverse (with different spacing) and longitudinal with and without dowels.

10. The subgrade consisted of 10 different soil types, some of which were treated with 1-inch and 2-inch layers of stone screenings and one and two layers of tar paper and one layer of Mosinee paper.

USING HAND FLOAT BEFORE BELTING



FINISHING CONCRETE SURFACE WITH LONG FLOAT

DETAILS OF VARIABLE FEATURES DESCRIBED

Cross section.—In the thickened edge design the subgrade was parabolic from the edge to the center. The pavement surface of the hand and machine finished sections was curved with a crown of 2¼ and 2 inches, respectively.

Finishing.—The tools for hand finishing consisted of a steel strike-off template 10 inches in width and weighing 600 pounds, a transverse wooden float 24 inches in width, and a belting machine. Six men, three at each end, manned the strike-off template. Three men spread the material and three tamped ahead of the template. In addition, two men spaded the material along the side forms. Generally three men were engaged in floating, belting, and finishing; two were employed in wetting and placing burlap.

The Vibrolithic concrete was mixed, deposited, and screeded as in the case of hand finishing. After screeding, coarse aggregate was applied uniformly to the surface at a rate of 50 pounds of stone per square yard and was vibrated into the fresh concrete by means of the vibrolithic platforms and motor carriages. Following this process, the pavement was finished in the usual manner with transverse float and belting machine.

Of the finishing machines, the Lakewood machine had the combination tamping and screeding features, while the Ord had only the screeding feature. Both machines were new and represented the latest model of the respective companies. It was possible to reduce the labor required by six men with the use of either machine, as compared to hand finishing.

Admixtures.—The hydrated lime, celite, and diatomaceous earth were used to determine their effect upon the workability and quality of the concrete. They were added dry to each batch of material at the proportioning plant, the percentages of each being based upon the weight of the cement. The Cal and calcium chloride were used as a substitute for surface curing. The former was added dry to the mix and the latter was first dissolved in water and was then added as the materials were being emptied into the drum of the mixer.

Curing.—Where concrete containing Cal and calcium chloride was laid the pavement surface was protected with wet burlap for 24 hours and then exposed to the weather without further attention. In the wet-earth method the earth covering was applied in a 2-inch layer within 24 hours after laying and was moistened twice a day for two weeks. The calcium chloride was applied to the surface within 24 hours in the dry state at a rate of 2 pounds per square yard. The sodium silicate was mixed with water in the proportions 1 part water to 3 parts sodium silicate and applied to the surface in such quantities as not to run or collect in pools. As in the case of the Cal and calcium chloride used as admixtures, no further attention or treatment was given the pavement surface. For all the various methods of curing the surface was covered with wet burlap during the initial 24-hour period.

Materials.—All materials were such as would be selected to obtain a first-class concrete. The two brands of cement (noted as A and B in Table 1) both conformed to the standard A. S. T. M. requirements and gave practically the same results in laboratory tests.

One of the two sands used (designated as sand A) was a washed river sand consisting largely of subangular and rounded grains of quartz, chert, sandstone, and gneiss, and had a silt content of 2.5 per cent. The other (sand B) was washed bank sand consisting largely of angular quartz particles with some grains of feldspar, and contained 0.5 per cent of silt.

The crushed stone was a local diabase rock, of exceptional quality, having a low absorption value, a high degree of toughness, and a low percentage of wear. The crusher-run material between the 2½-inch and ¼-inch round screens was used.

The gravel was a washed bank material consisting mainly of rounded fragments of quartz and chert. The maximum and minimum sizes of the coarse gravel

(No. 1) corresponded to that of the stone, while the fine gravel (No. 2) ranged from 1½ inch to ¼ inch. Representative test results of the various aggregates are given in Table 2.

TABLE 2.—*Test results of aggregates for concrete*

MECHANICAL ANALYSIS

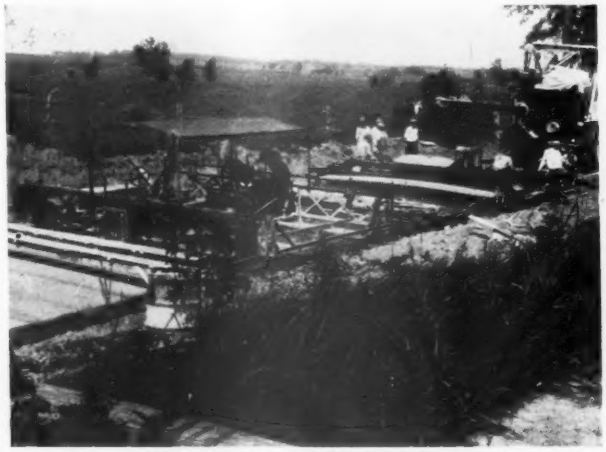
Sieve	Total retained					
	Stone A	Stone B	Gravel No. 2	Gravel No. 1	Sand A	Sand B
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
2-inch	16.0	20.0	0	5.6		
1½-inch	39.6	44.4	0	24.2		
¾-inch	78.3	79.0	37.0	72.3		
¼-inch	97.0	97.4	94.2	94.7		
No. 10					16.0	25.0
No. 20					30.3	54.4
No. 50					84.0	95.0
No. 100					95.4	99.2

PHYSICAL PROPERTIES

	Stone A	Stone B	Gravel No. 2	Gravel No. 1	Sand A	Sand B
Percentage of wear	2.8	3.0	13.4	13.4		
Hardness	18.7	19.0				
Toughness	18.0	18.0				
Absorption, per cent	0.10	0.08	0.36	0.36		
Weight per cubic foot, pounds	186	188	163	163		
Silt, per cent					2.25	0.5
Strength ratio at 7 days, per cent					103	103
Strength ratio at 28 days, per cent					103	

STONE QUARRY

Correction for the bulking of the sand was not made in the 1 : 2 : 4 mix used in sections 1 to 25 and 44 and 45 in the 1 : 1½ : 3 mix (sections 43 A and 43 B), in the 1 : 2½ : 3½ mix (section 9), or in the 1 : 3 : 3½ mix (section 38). In all other cases the 1 : 2 : 4 mix was corrected for bulking and approached a field mix of 1 : 2½ : 4 proportions.



GENERAL VIEW OF FINISHING OPERATIONS

Reinforcement.—The sections in which reinforcement was used and the details of the mats together with related information are given in Table 3.

Joints.—Construction joints formed by removing a wooden header and laying the new concrete directly against the old were installed at noon and night on project 336 C and on section 45 of project 336 D. On projects 336 D and E, ½-inch expansion joints were placed every 40 feet for a distance of 500 feet on each side of all bridges. Otherwise, ½-inch bituminous felt expansion joints were installed at noon and night on project 336 D (section 45 excepted), while a double thickness of the same material was installed in a like manner in the sections of 336 E.

Planes of weakness.—The planes of weakness or impressed grooves were approximately 2½ inches deep by one-fourth inch wide at the base and from one-half inch to 1 inch wide at the top and were installed with a special machine, the Flex-Plane. The machine bridged the pavement slab and traveled on the side forms immediately behind the hand screeds or finishing ma-

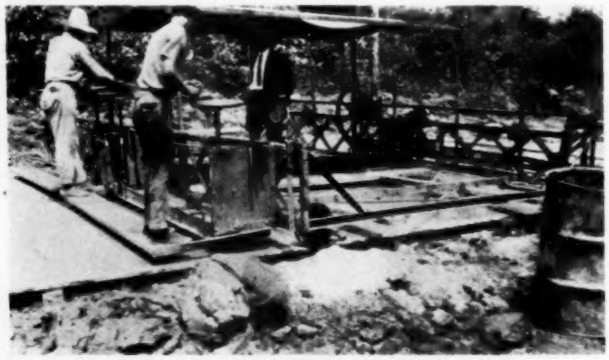
TABLE 3.—*Details of reinforcing mats*

Type	Sections	Planes of weakness		Joints		Weight per 100 square feet	Strands			Lap	Depth from surface
		Transverse spacing	Longitudinal	Construction	Expansion		Shape	Diameter	Spacing		
						Pounds				*Inches*	
One layer welded fabric	7	None	None	Noon and night.		42	Round	6-gauge	6 by 6 inches	6	2½ inches.
	33	40 and 100 feet	Groove		Noon and night	42	do	do	do	6	Do.
	41	do	None		do	42	do	do	do	6	Do.
Two layers welded fabric	8	None	do	Noon and night.		85	do	do	do	6	2¼ inches (upper layer).
	9	do	do	do		85	do	do	do	6	Do.
One layer expanded metal	32	40 and 100 feet	Groove		Noon and night	42	Square		Diamond	6	2½ inches.
	40	do	None		do	42	do		do	6	Do.
One layer bar mat [1]	30 A	do	Groove		do	50	Round	⅝-inch	21 by 24⅜ inches	15	Do.
	30 B	None	do		40-foot centers	50	do	do	do	15	Do.
	37 A, 37 B	40 and 100 feet	None		Noon and night	50	do	do	21 by 21 inches	15	Do.
Two layers bar mat	36	do	do		do	100	do	do	do	15	2¼ inches (upper layer).

[1] All bar mats have two marginal bars 4 inches apart. Mats (sections 30 A and B) have in addition a longitudinal bar on each side of the longitudinal plane of weakness spaced 6 inches apart; other longitudinal bars are spaced at 24⅜ inches.

chines. It was used to install both longitudinal and transverse grooves and was adjustable so that it could be used on pavements up to 24 feet in width.

When a longitudinal groove was being installed a spading tool which operates as the machine is propelled forward first opened a preliminary groove by displacing or pushing aside the coarse aggregate. After the



Using the Flex-Plane Apparatus

machine has been moved forward a distance of 10 feet a V-shaped metal form was forced into the depression by means of a mandrel and two compression screws on the machine. The mandrel was then raised and moved out of line. The machine was again propelled forward and another form placed. These two forms are then connected and held in horizontal alignment by an expanding bar. In the installation of a transverse groove a form is set on a mandrel and forced into the undisturbed pavement surface by means of compression screws. In some instances considerable difficulty was experienced in the installation of the transverse grooves.

As a general rule the expanding bar and V forms were removed the morning following their installation. No trouble was experienced in removing the forms when the concrete adjacent to them had been edged. The accompanying illustrations show the manner in which the metal forms are lifted and a view of a transverse and longitudinal groove formed by this method.

The planes of weakness were installed transversely only, longitudinally only, in combination, and in combination with a longitudinal steel center joint. Table 4 gives details of the sections involving these planes of weakness combinations.

In the sections where reinforcement was used in combination with the longitudinal plane of weakness the steel mats were continuous across the slab. In a number of sections the slabs formed by longitudinal planes of weakness were connected by dowels, but in no instance were the slabs formed by transverse planes of weakness connected by dowels or reinforcement.

Two sections (27 and 28) were constructed with a tongue-and-groove doweled center joint for comparison with sections having the longitudinal plane of weakness.

Subgrade.—Ten different types of soil are represented in the natural subgrade. The character of these various types ranges from a friable, well-drained shale to a dense impervious clay. The heavy grading and bridge work was generally completed the same year as the paving. No artificial drains were used in the experimental sections and, excepting an occasional layer of stone screenings and both double and single layers of tar paper on certain sections, no special

Table 4.—*Details of sections involving planes of weakness*

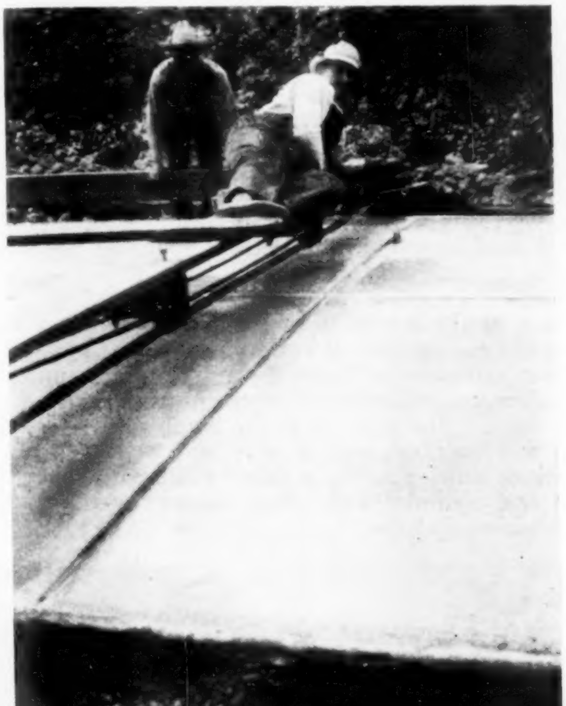
Planes of weakness	Section	Spacing of transverse planes	Spacing of dowels across longitudinal plane	Joints		Reinforcement	Coarse aggregate	Curing	Admixtures
				Construction	Expansion				
		Feet	*Feet*						
Transverse	26 D	40 and 100			Noon and night		Stone A	Wet earth	Diatomaceous earth, 3 per cent.
	34	do			do		do	$CaCl_2$, surface	
	35 A	do			do		do	$CaCl_2$, mixed	$CaCl_2$, 2 per cent.
	36	do			do	Bar mat, 2 layers.	do	Wet earth	
	37 A	do			do	Bar mat, 1 layer.	do	do	
	38	do			do		do	do	
	39	do			do		do	do	Celite, 3 per cent.
	40	do			do	Expanded metal, 1 layer.	do	do	
	41	do			do	Welded fabric, 1 layer.	do	do	
	42 A and B	do			do		do	do	
	43 A and B	do			do		do	do	
	44	do			do		do	do	
Longitudinal only	12 to 19			Noon and night			do	do	
	29				60-foot centers		do	do	
	30.B				40-foot centers	Bar mat, 1 layer.	do	do	
	31		5		Night		do	do	
	46 A		5		Noon and night		Gravel No. 2	do	
	47 A		5		do		Gravel No. 1	do	
	48 A		5		do		Stone B	do	
Transverse and longitudinal.	20 and 21	40		Noon and night			Stone A	do	
	22	do		do			do	do	
	30 A	40 and 100			Noon and night	Bar mat, 1 layer.	do	do	
	32	do			do	Expanded metal, 1 layer.	do		
	33	do			do	Welded fabric, 1 layer.	do	Wet earth	
	46 B	30, 40, and 50	5		do		Gravel No. 2	do	
	47 B	do	5		do		Gravel No. 1	do	
	48 B	do	5		do		Stone B	do	
	49	40	5		do		do	do	
	50	do	5		do		do	Na_2SiO_3 (sur)	
	51	do	5		do		do	$CaCl_2$, mixed	$CaCl_2$, 2 per cent.
	52	do	5		do		do	Cal, mixed	Cal, 5 per cent.
Transverse with steel center joint.	28 A	40 and 100	5		do		Stone A	Wet earth	

treatment was given the subgrade. The stone screenings were used more to expedite construction than as a subgrade treatment.

Weather.—In addition to the normal daily variation in temperature, humidity, and wind velocity, seasonal variations in weather from early spring to late fall were encountered.

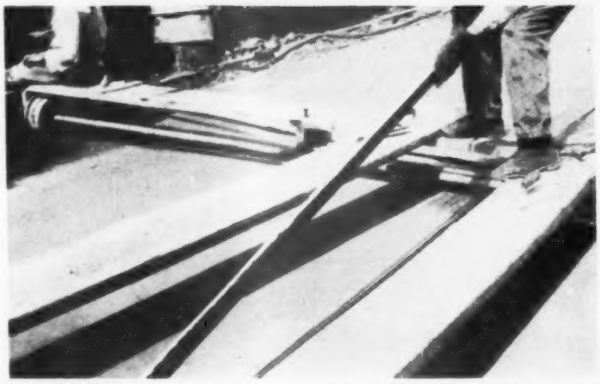
CONSTRUCTION OPERATIONS CLOSELY OBSERVED

From two to four observers from the Bureau of Public Roads were assigned to the project to obtain information on the construction and behavior of the different sections. As a general rule representatives of interested commercial organizations assisted in

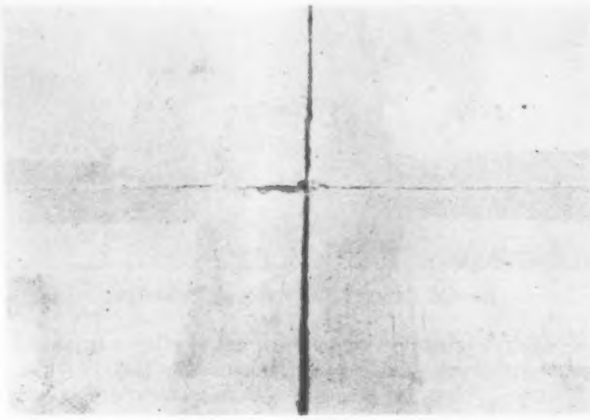


FINISHING LONGITUDINAL AND TRANSVERSE PLANES OF WEAKNESS WITH STEEL STRIPS IN PLACE

TRANSVERSE AND LONGITUDINAL PLANES OF WEAKNESS



REMOVING STRIP FROM LONGITUDINAL PLANE OF WEAKNESS



LONGITUDINAL PLANE OF WEAKNESS JUST AFTER REMOVAL OF STRIP

familiarizing the organization with special construction features of the sections or with the operation of special equipment. The observations included the following:

Subgrade.—The number of soil types, their marked difference in character, and the variety of subgrade conditions encountered suggested that special emphasis be placed upon this phase of the investigation. A general survey was made, in cooperation with the Bureau of Chemistry and Soils of the Department of Agriculture, showing the location and extent of the soil types, the thickness of the layers, and variations in character within the types. Representative samples of the different layers of the various types were selected and tested in the laboratory of the Bureau of Public Roads. Samples were also taken from the finished grade at every station immediately prior to paving and tested in the same manner.

Data collected during the progress of the preliminary and final grading and immediately prior to paving were as follows:

1. Time of preliminary and final grading with respect to the time of placing the concrete.
2. Condition of the soil with respect to its moisture content, type of hauling, and intensity and frequency of rolling during heavy grading.
3. Condition of the soil with regard to compactness, degree of smoothness or rutting prior to paving.
4. Nature and extent of underlying shale and rock and their position relative to the pavement. Information was obtained from the landowners along the right of way pertaining to the nature and location of underground springs and seepage areas.

The accompanying illustration shows a subgrade condition resulting from the variable stability of the soil encountered in certain locations. All such outstanding conditions that existed or developed in the grade during the course of construction were fully described and classified and it is expected that information concerning the influence of such conditions upon slab behavior will be obtained from these locations.

BADLY RUTTED SECTION OF SUBGRADE

Weather.—Hourly observations of the atmospheric conditions were made throughout the period of construction. Such information as temperature, relative humidity, degree of clearness, and intensity of prevailing winds were obtained, as well as the amount of rainfall.

Materials.—Inspection was maintained at all times as to the quality and quantity of the materials being used in the concrete. Tests for gradation were made on representative samples of the coarse and fine aggregate from each day's run. In addition, four samples of sand were collected each day, on which moisture determinations were made. These latter tests were primarily for the purpose of computing the water-cement ratio of the mix and for correction for bulking of the sand induced by moisture variations. Each car of cement was sampled and tested in accordance with the specifications of the Virginia Highway Commission. During construction of project 336 E in 1927 samples of cement were obtained and tested from those batches from which the beam and cylinder specimens were made.

Admixtures and curing agents.—The effect of integral materials upon the workability and yield of the concrete was observed. Ease of handling and finishing were considered as measures of workability. Yield data were obtained from records of number of batches and thickness and length of pavement.

Steel reinforcement.—Observations were made concerning the depth of the steel mats from the surface, the degree of lapping of the mats, and the additional labor necessary to handle and install the mats in the pavement.

Finishing methods.—Observations on the different methods of finishing included the amount of labor, the relative compactness of the mass after the operation, and the effect upon the vertical and horizontal alignment of the forms.

Condition surveys were made 24 hours after placing when the wet burlap was removed and after the curing period, which was about one month. Future surveys are to be made each spring and fall. The surveys include observations of the developed surface and slab defects, such as checking, cracking, breakage, and faulting. The behavior of the planes of weakness and expansion joints is also observed.

Record charts.—A graphic chart was made to correlate and show in a condensed manner the results of observations made during the construction of the road. Figure 1 shows a typical record covering about 1,000 feet of pavement slab.

These records give in detail the time of depositing the concrete and the time of finishing and covering the pavement with wet burlap. They give the slump, the water-cement ratio, and the temperature of the concrete at the time of depositing. The condition of the atmosphere as regards wind, clearness, humidity, and temperature when the concrete was poured is shown. They indicate the thickness of the slab at 25-foot intervals and contain information on the subgrade such as a description of the soil type and condition of the grade immediately prior to paving. The depth and extent of the cuts and fills at the center line of the road and the relative position of the ground line on either side are shown by a profile. They give a picture of the condition of the pavement at 24 hours after the curing periods and at subsequent periods.

Test specimens.—Three 6 by 12 inch compression cylinders were cast from a representative batch of each day's run. The location of the batch in the pavement slab was marked, and a core was drilled from the location subsequent to the curing period. The core and cylinder were then tested in compression simultaneously.

TYPICAL CONDITION OF PAVEMENT IN MAY, 1928

On project 336 D and in sections 46, 47, and 48 of project 336 E, in addition to the compression cylinders, five 6 by 6 by 30 inch beams were cast each day from the same batch of material. These were cured in a manner similar to the pavement slab and were tested by bending (cantilever method) at ages of 7, 14, 21, 28, and 90 days. In sections 49, 50, 51, and 52, a special study of curing methods was made, and a total of 320 beams was cast, 80 to each section. On each

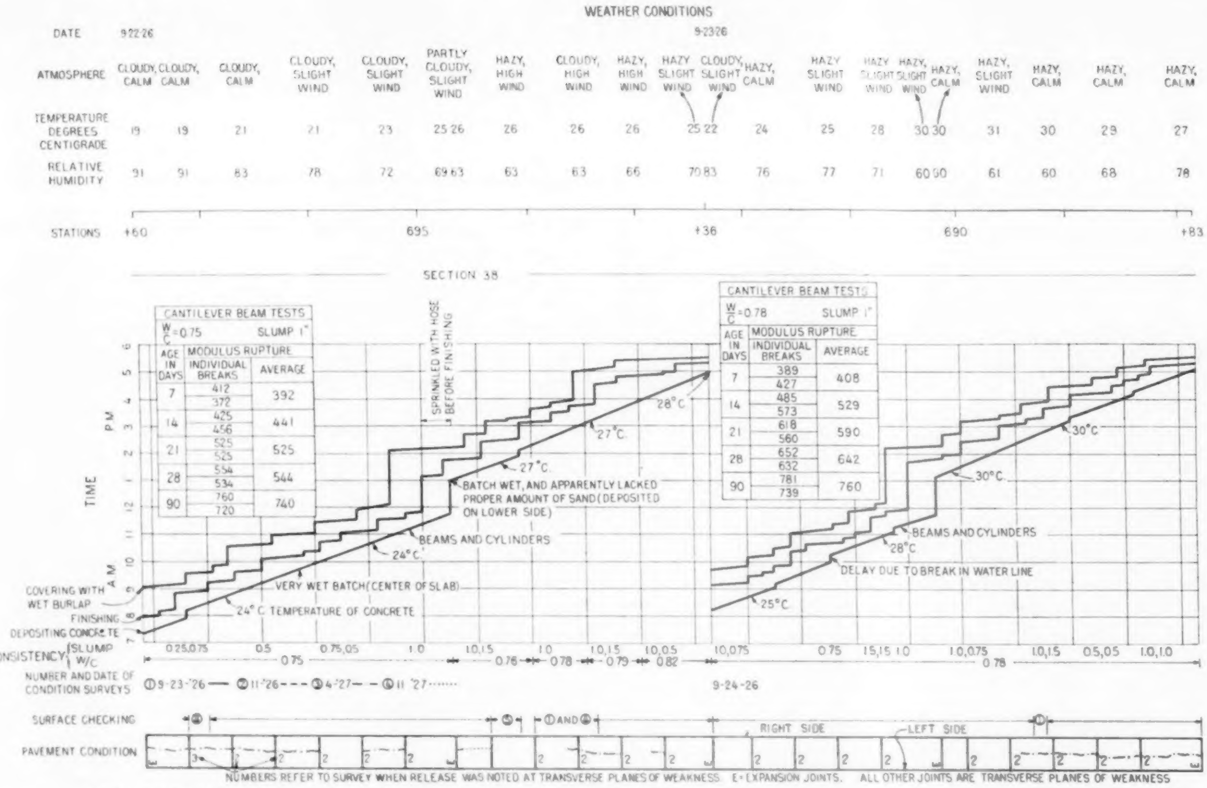


FIG. 1.—TYPICAL RECORD OF CONSTRUCTION OPERATIONS AND CONDITIONS. THE CONDITION OF THE SUBGRADE AND SURFACE CHECKING ARE EACH INDICATED BY CODE NUMBERS, THE KEY TO WHICH IS NOT GIVEN

section 20 beams were cast on four different days, and half of the number were cured in the same manner as the pavement slab, while the other half were exposed to the weather after the usual protection for 24 hours with wet burlap. These specimens were tested at 1, 2, 3, 5, 7, 14, 28, 90, 180, and 360 days, respectively.

Proposed studies in connection with the project include a study of the relative smoothness of the sections and of the influence of different types of joints upon the riding qualities of the surface. A study has also been suggested concerning the load-transferring properties of the longitudinal plane of weakness as compared to the steel center joint.

This report is limited primarily to a description of the project and a brief discussion of the nature of the data obtained during its construction. Later reports will deal more directly with particular phases of the investigation.

RESISTANCE OF PORTLAND CEMENT CONCRETE TO THE ACTION OF SULPHATE WATERS AS INFLUENCED BY THE CEMENT [1]

By DALTON G. MILLER, Drainage Engineer, Division of Agricultural Engineering, United States Bureau of Public Roads

IN CONNECTION with investigations of the action of sulphate waters on concrete draintile, laboratory experiments with cement concrete cylinders made with 12 standard Portland cements and stored in 1 per cent solutions of sodium sulphate (Na_2SO_4) indicated great differences in resistance to disintegration, as previously reported.[2] The experiments were therefore broadened to include 18 other cements and also check tests of cylinders made of 22 of the 30 cements and exposed to the mixed salts of the natural alkali waters of Medicine Lake, S. Dak., 18 miles northwest of Watertown.

Analyses of water samples taken from Medicine Lake at different seasons of the year have shown a total salt content ranging between 2.34 and 4.72 per cent, consisting almost entirely of magnesium and sodium sulphates. An average of four analyses of water samples taken December 10, 1923, February 14, 1924, April 29, 1924, and July 1, 1925, are given in Table 1.

TABLE 1.—*Average of four analyses of water from Medicine Lake, S. Dak.*[1]

RADICALS

Na (Calc)	Ca	Mg	NO_3	Cl	SO_4	CO_3	HCO_3	Total
MILLIGRAMS PER LITER (PARTS PER 1,000,000)								
3,036	717	5,079	1	509	27,021	88	313	36,764
PERCENTAGE REACTING VALUES								
10.38	2.93	36.69	0.01	1.01	48.22	0.30	0.46	100.00

[1] Analyses by the water and beverage laboratory, Bureau of Chemistry and Soils, U. S. Department of Agriculture.

TEST CYLINDERS DESCRIBED

Each series of test cylinders consisted of five batches made on different days, and nine 2 by 4 inch cylinders were made from each batch. The cylinders were mixed in the proportion of 1:3 by volume with a relative consistency of 1 and water-cement ratios ranging between 0.59 and 0.64, as shown in Tables 2 and 3. The aggregate passed all standard physical tests and was separated into screen sizes and recombined for each batch to produce a fineness modulus of 4.67. The cylinders to be stored in solutions in the laboratory were cured 1 day in the moist closet, followed by 20 days in distilled water, and at 21 days were transferred to earthenware jars containing 2.6 gallons of 1 per cent solution of sodium sulphate (Na_2SO_4), 20 cylinders to a jar. All solutions were changed at the end of the first week, after which they were changed every two weeks for the first year and, following the one-year test, were changed every four weeks.

The cylinders in those series to be stored in Medicine Lake were cured 1 day in the moist closet and 20 days in distilled water, and then hardened 5 weeks in air in the laboratory. Excepting for this air hardening period there was no intentional difference between the cylinders stored in the laboratory solutions and those in Medicine Lake. Check cylinders in all cases were stored in tap water in the laboratory tank.

In certain of the tables and figures reference is made to the "life" of different series. By this is meant the average time in weeks required for ten 2 by 4 inch cylinders to each increase in length 0.01 inch (0.25 of 1 per cent). Many tests in the laboratory, dating from 1921, have shown that such an increase in length for cylinders of this type of concrete stored in sodium and magnesium sulphate solutions is indicative of strength losses of 50 to 65 per cent. A general discussion of this method of rating was presented in an

TABLE 2.—*Tests of 2 by 4 inch concrete cylinders, 1:3 mix, made of Portland cements from different plants and stored in 1 per cent solutions of sodium sulphate (Na_2SO_4)*

[Each result is average for 5 or 10 cylinders made on five different days]

Cement laboratory No.	Series No.	Water-cement ratio	Absorption at 21 days	Average of compression tests: Stored in water, 7 days	Stored in water, 28 days	Stored in water, 1 year	Stored in solutions, 1 year	Stored in solutions, 2 years	Life
			Per cent	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Weeks*
40	267	0.60	5.60	3,310	4,600	6,480	5,310	5,760	[1] 210
97	379	.64	6.11	2,710	4,610	6,000	5,850	4,890	[1] 165
79	376	.62	5.90	3,180	4,640	6,410	5,520	4,490	[1] 165
41	265	.60	5.51	3,460	4,790	5,860	5,930	4,280	[1] 165
42	268	.62	6.26	2,450	3,580	6,220	4,900	4,090	[1] 165
34	275	.67	6.20	3,160	4,970	5,730	5,040	4,050	[1] 165
35	262	.60	5.85	3,010	4,630	6,250	5,070	3,860	[1] 150
113	473	.64	6.17	1,960	4,240	5,580	4,840	-------	[1] 140
37	263	.60	6.26	3,180	4,820	5,740	4,600	2,240	115
98	380	.64	5.83	3,710	5,380	6,240	5,150	2,430	[1] 110
102	408	.62	5.62	4,030	5,970	5,890	4,780	1,840	[1] 96
105	411	.62	5.85	3,560	5,450	6,220	4,360	1,550	92
39	264	.60	5.84	3,280	5,020	6,080	4,790	1,910	88
106	417	.62	6.18	2,930	4,810	6,040	3,890	0	87
65	312	.60	6.01	3,090	4,270	4,910	2,930	0	78
107	418	.62	6.53	3,050	4,340	5,410	3,310	0	75
55	269	.62	6.37	2,960	4,280	5,650	3,510	1,390	73
103	409	.62	6.04	3,530	5,480	6,480	4,030	1,330	72
110	470	.64	6.01	3,660	5,090	5,560	2,160	0	71
108	419	.62	5.80	3,690	4,970	5,550	2,610	0	63
101	407	.62	5.72	3,800	5,760	6,690	3,030	0	59
89	378	.62	5.56	4,200	4,890	6,550	2,400	0	50
88	377	.64	5.72	3,570	4,950	6,660	2,150	0	49
63	272	.60	5.75	2,390	4,610	5,950	1,900	0	49
60	270	.60	6.07	2,300	3,850	6,380	[2] 1,900	0	42
33	274	.60	5.74	3,170	4,880	5,950	[3] 1,730	0	36
62	273	.62	5.62	2,480	4,470	5,760	[4] 1,640	0	32
104	410	.62	6.51	3,030	4,870	5,160	[5] 2,000	0	30
111	471	.64	5.94	3,420	4,960	6,050	[6] 2,210	0	29
100	406	.62	6.42	2,860	4,980	5,740	[7] 1,950	0	27
Average		.62	5.97	3,170	4,810	5,970	3,650	1,470	92

[1] Estimated from change in length.
[2] Tested at 37 weeks.
[3] Tested at 35 weeks.
[4] Tested at 45 weeks.
[5] Tested at 30 weeks.
[6] Tested at 33 weeks.
[7] Tested at 39 weeks.

[1] Paper presented before the American Society for Testing Materials at Atlantic City, June, 1928, and also reported as Univ. of Minn. Paper No. 779, Jour. Ser. This paper is the result of experiments at University Farm, St. Paul, Minn., in the draintile laboratory conducted by the department of agriculture of the University of Minnesota and the U. S. Department of Agriculture.

[2] FOUR IMPORTANT FACTORS IN THE MANUFACTURE OF CONCRETE PIPE FOR ALKALI SOILS. Transactions of the Amer. Soc. Agr. Engineers, vol. 20, p. 180. (1926.)

TABLE 3.—*Tests of 2 by 4 inch concrete cylinders, 1:3 mix, stored in Medicine Lake, S. Dak. Cylinders made of cements from the same lots that were used in the cylinders of Table 2*

[Each result is average of five cylinders made on different days]

Cement laboratory No.	Series No.	Water-cement ratio	Absorption at 21 days	Average of compression tests: Stored in water, 7 days	Stored in water, 28 days	Stored in water, 1 year	Medicine Lake, 1 year
			Per cent	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*
40							
97	372	0.64	6.4	3,120	4,440	5,720	4,600
79	362	.62	6.1	3,220	4,600	6,170	4,000
41							
42							
34	260	.66	6.1	3,340	4,540	5,980	5,090
35							
113	468	.64	6.3	2,140	3,940	6,000	5,590
37							
98	373	.64	6.1	4,220	4,970	7,050	3,400
102	403	.62	5.9	3,860	5,640	6,630	4,410
105	413	.62	5.7	3,520	5,390	6,500	4,300
39							
106	414	.62	6.1	3,030	4,410	6,430	2,490
65	313	.60	5.9	3,150	3,950	6,050	2,250
107	415	.62	6.5	2,830	4,540	5,920	2,940
55							
103	404	.62	6.0	3,010	4,380	5,470	3,160
110	465	.64	5.5	3,660	4,920	6,910	4,850
108	416	.62	5.8	3,670	5,010	6,510	1,490
101	402	.62	6.3	3,680	4,940	6,290	2,440
89	363	.62	5.9	4,010	5,220	6,730	670
88	370	.64	6.1	3,730	5,040	6,540	810
63	257	.59	5.8	2,720	4,290	5,490	3,190
60							
33	259	.59	5.4	3,340	4,780	5,900	1,590
62	258	.59	5.8	2,960	3,790	4,580	800
104	405	.62	6.4	2,940	4,380	5,530	280
111	466	.64	5.7	3,810	5,020	5,860	3,920
100	401	.62	6.4	2,900	4,310	5,110	0
Average		.62	6.0	3,310	4,660	6,060	2,830

earlier report.[3] Throughout this paper the order of arrangement of the data in all tables and figures is the same as the "life" as recorded in the last column of Table 2.

Results of tests of the cylinders stored in the laboratory solutions are compiled in Table 2 and shown graphically in Figure 1. Figure 2 illustrates the wide range of condition of cylinders of different series at two years. Results of tests of the cylinders stored in Medicine Lake are given in Table 3. The strength ratios of cylinders at one year, for both exposure conditions, have been calculated assuming normal strength to be that of the check cylinders from the laboratory tank. These results for the 22 cements subjected to the two different exposure conditions are set forth in Table 4.

TABLE 4.—*Tests of cylinders made with 22 cements under two different exposure conditions at one year*

Cement laboratory No.	97	79	34	113	98	102	105	106	65	107	103	110	108	101	89	88	63	33	62	104	111	100
	Per cent of normal strength at one year																					
Stored in 1-per cent solution of Na_2SO_4	98	86	88	87	83	81	70	64	60	61	62	39	48	41	37	32	32	0	0	0	0	0
Stored in Medicine Lake	80	57	85	93	48	67	66	39	37	50	58	70	23	39	10	12	58	27	17	5	68	0

It is apparent from the data of Table 4 that, while all of the 22 cements have not acted entirely consistently,

[3] MILLER, DALTON G. VOLUME CHANGE A MEASURE OF ALKALI ACTION. Public Roads, vol. 5, No. 4, June, 1924.

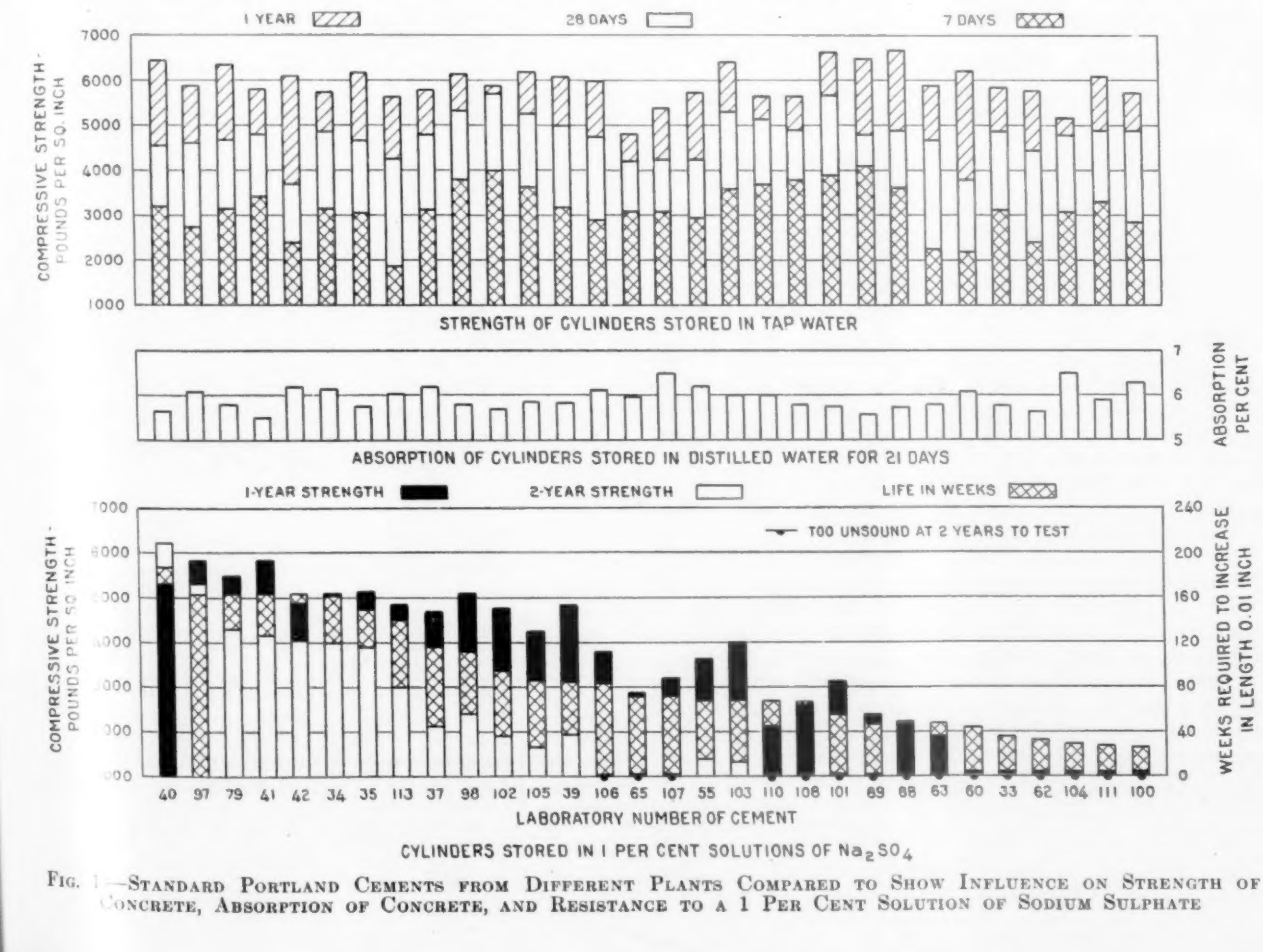


FIG. —STANDARD PORTLAND CEMENTS FROM DIFFERENT PLANTS COMPARED TO SHOW INFLUENCE ON STRENGTH OF CONCRETE, ABSORPTION OF CONCRETE, AND RESISTANCE TO A 1 PER CENT SOLUTION OF SODIUM SULPHATE

the inconsistencies have been few and none of the cements making either an exceptionally good or an exceptionally poor test under one condition showed a complete reversal under the other condition, with the possible exception of cement No. 111.

PHYSICAL TESTS OF CEMENTS DO NOT FURNISH INDEX OF RESISTANCE TO SULPHATE WATERS

Results of the standard physical tests of the 30 cements are shown in Figures 3, 4, and 5, and it requires but cursory study to see the futility of using any of the standard physical tests as an index of the behavior of any particular Portland cement in resisting the action of sulphate-bearing waters.

A special fineness test was made on 7 of the 30 cements, selected because of extreme showings made under exposure conditions, and the results of these tests are recorded in Table 5. It is obvious from Table 5 and Figure 5 that the difference in fineness, however considered, is so slight as not to account for a difference in the cements.

Fig. 2.—Condition of Cylinders from Series 379, 417, and 406 at End of Two Years, Showing Wide Differences in Resistance to Sulphate Water

CHEMICAL ANALYSES DO NOT PRODUCE RESULTS ON WHICH TO BASE CONCLUSIONS

Standard chemical analyses of all of the cements are recorded in Table 6. As would be expected, there are differences in chemical composition, but authorities on the chemistry of Portland cements are not in complete agreement as to the principal compounds formed by the various constituents, and it is therefore not known that these chemical analyses can be so interpreted as to be of value.

The data of Table 6 have been condensed and considered in Table 7 on the basis of averages by dividing the 30 cements into three groups. Group 1 contains the first 10 cements of Table 6, Group 2 the second 10, and Group 3 the last 10. The average life of cylinders for the three groups (see Table 2) has been, respectively, 155, 79, and 40 weeks, the "life" ratio for the groups closely approximating 4 : 2 : 1.

Examination of the data as averaged in Table 7 fails to disclose any decided trend that appears to be of enough significance to account for the differences in resistance of the cements of the three groups. It is interesting to note, though, that the nearest approach to a trend is in the percentage of alumina, which, considered with the percentage of iron oxide, lends support to the theory of Le Chatelier[4] of long ago that Portland cements low in alumina and high in iron are resistant to sea water. Unfortunately for this theory,

[4] Le Chatelier, Henri. Search for materials capable of resisting sea water. Annales des Mines, May and June, 1887.

Table 5.—*Special fineness tests of seven Portland cements differing widely in resistance to alkali*

[Analyses, other than 200 sieve, were made by Bureau of Standards, U. S. Department of Commerce [1]]

Cement laboratory No.	Series in which used	Passing 200 sieve	Passing 325 sieve	Under— 60 microns	40 microns	20 microns	10 microns
		Per cent	Per cent	Per cent	Per cent	Per cent	Per cent
40	267	84.7	74.7				16.5
41	265	84.1	74.6	66.2	52.1	34.0	15.9
34	260, 275	90.9	82.8				18.2
55	269	83.8	75.3	65.3	51.9	34.3	17.0
63	257, 272	81.8	70.3				16.2
33	259, 274	82.1	71.9				15.9
62	258, 273	83.0	72.6	67.7	53.1	36.6	19.2

[1] A description of the apparatus may be found in the Bureau of Standards Technologic Paper No. 48.

Table 6.—*Standard chemical analyses of Portland cements used*

[Chemical analyses by the Division of Tests]

Cement laboratory No.	Series No.	Silica (SiO_2)	Iron oxide (Fe_2O_3)	Alumina (Al_2O_3)	Lime (CaO)	Magnesia (MgO)	Sulphuric anhydride (SO_3)	Loss on ignition	Total
		Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent
40	267	21.71	3.39	6.53	62.50	1.59	1.77	1.84	99.33
97	379	21.45	2.65	6.45	62.50	2.97	1.82	1.95	99.79
79	376	22.85	4.27	4.93	61.70	1.92	1.25	3.10	100.02
41	265	21.13	2.73	8.89	62.40	.49	1.78	1.29	98.71
42	268	20.47	3.58	6.24	61.82	3.94	1.85	1.95	99.85
34	275	22.43	3.20	5.03	62.54	3.75	1.91	1.20	100.06
35	262	21.93	3.42	6.31	62.29	3.44	1.33	1.22	99.94
113	473	24.87	2.39	4.57	61.30	1.26	1.58	3.60	99.57
37	263	21.55	2.89	8.51	60.64	1.85	1.94	2.09	99.47
98	380	22.90	2.82	5.88	63.70	.94	1.72	1.95	99.91
102	408	21.74	3.10	6.38	63.06	1.99	1.76	1.47	99.50
105	411	22.45	2.33	5.92	62.70	1.79	1.87	2.70	99.76
39	264	20.82	3.10	7.52	62.75	1.12	1.64	2.10	99.05
106	417	22.40	3.22	6.83	62.65	1.34	1.22	2.15	99.81
65	312	21.80	2.57	7.69	62.05	2.46	2.16	1.18	99.91
107	418	21.50	2.80	6.30	62.08	1.21	1.80	3.70	99.39
55	269	21.52	2.78	6.25	61.78	3.78	2.01	1.47	99.59
103	408	21.52	3.30	5.63	61.40	5.00	1.34	1.53	99.72
110	470	22.40	2.42	6.48	63.05	1.76	1.49	2.20	99.80
108	490	21.15	2.70	7.40	63.35	1.77	1.37	2.25	99.99
101	407	21.70	2.70	6.59	64.19	1.27	1.66	1.55	99.66
89	378	21.60	3.46	5.04	62.75	2.68	1.68	2.75	99.96
88	377	22.50	3.06	6.39	62.95	1.30	1.56	2.25	100.01
63	272	22.66	2.51	8.12	61.87	1.05	1.72	1.60	99.53
60	270	22.22	3.20	8.06	62.60	.59	1.47	1.46	99.60
33	274	21.12	2.48	6.82	61.24	5.24	2.01	1.90	100.81
62	273	20.53	2.14	9.61	63.06	1.56	1.72	1.26	99.80
104	410	20.73	2.85	6.23	61.16	4.95	1.61	2.06	99.59
111	471	20.97	4.19	6.71	63.43	1.45	1.65	1.54	99.94
100	406	21.28	3.14	7.72	61.33	2.65	1.53	1.90	99.55
Av.		21.80	2.98	6.70	62.36	2.24	1.67	1.97	99.72

Table 7.—*Results of Table 6 condensed by dividing cements into three groups and averaging results of analyses for each group*

Group	Silica (SiO_2)	Iron oxide (Fe_2O_3)	Alumina (Al_2O_3)	Lime (CaO)	Magnesia (MgO)	Sulphuric anhydride (SO_3)	Loss on ignition	Total
	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent
1	22.13	3.13	6.33	62.14	2.22	1.70	2.0[illegible]	99.67
2	21.73	2.83	6.64	62.49	2.22	1.67	2.0[illegible]	99.65
3	21.53	2.97	7.13	62.46	2.27	1.66	1.8[illegible]	99.85

TABLE 8.—*Lime-silica indexes of 30 cements*

Cement laboratory No.	Lime-silica index	Cement laboratory No.	Lime-silica index
40	2.16	107	2.24
97	2.26	55	2.19
79	2.14	103	2.25
41	2.07	110	2.21
42	2.27	108	2.27
34	2.21	101	2.31
35	2.16	89	2.33
113	2.04	88	2.17
37	1.91	63	1.97
98	2.21	60	2.02
102	2.24	33	2.18
105	2.22	62	2.14
39	2.21	104	2.29
106	2.14	111	2.27
65	2.11	100	2.11

reference to individual analyses of cements in the three groups (see Table 6) show several outstanding inconsistencies for which no ready explanation is evident.

LIME-SILICA INDEX CONSIDERED

It has been suggested [5] that the "lime-silica index" should be considered in determining the quality of a cement. Following the method outlined in the reference given, the lime-silica index has been calculated for each of the cements and are shown in Table 8. It is not apparent how these results, which differ only slightly, are of value in considering the relative resistance to the action of sulphate waters.

[5] MERRIMAN, THADDEUS. LIME-SILICA INDEX AS MEASURE OF CEMENT QUALITY. Engineering News-Record, vol. 96, No. 16, 1926.

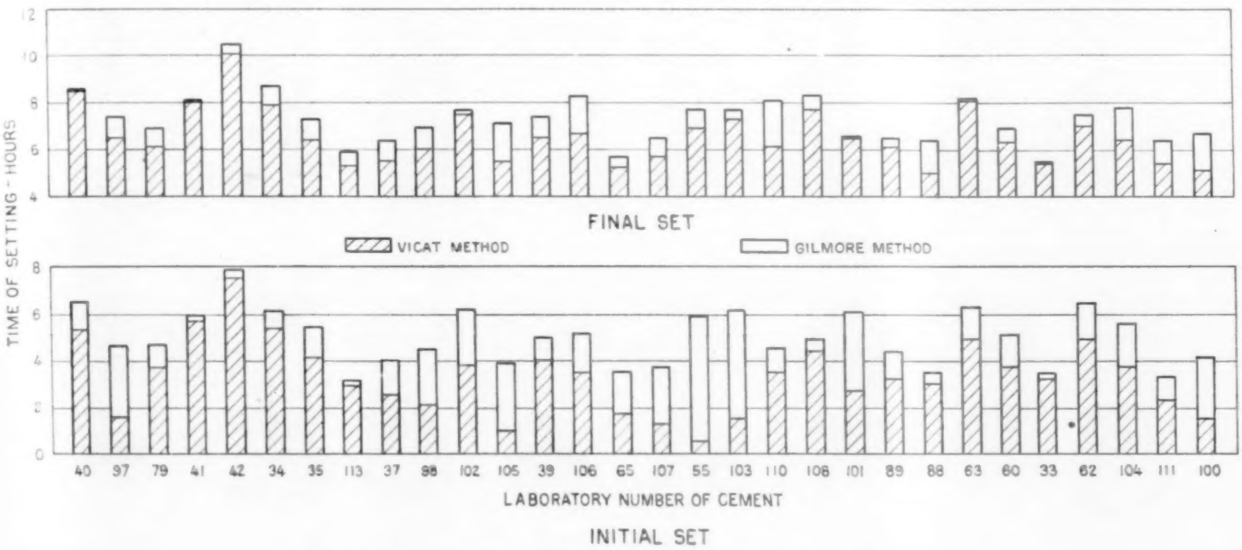


FIG. 3.—RESULTS OF STANDARD TESTS FOR TIME OF SETTING

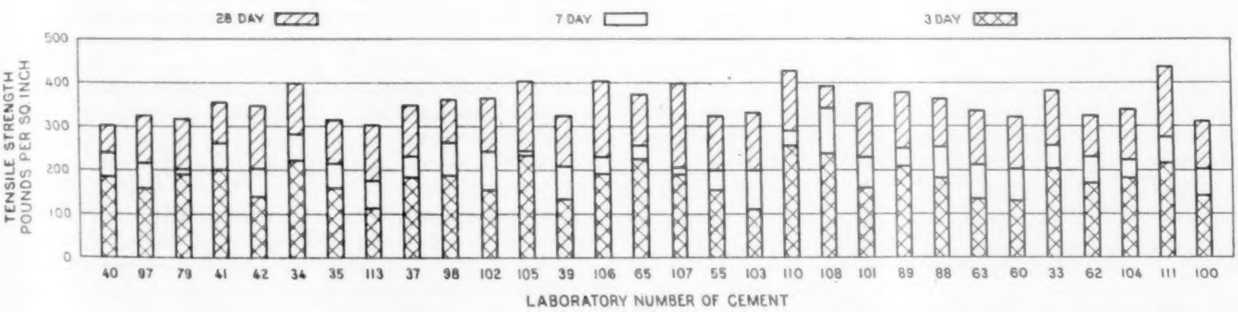


FIG. 4.—RESULTS OF STANDARD TENSILE TESTS OF BRIQUETS

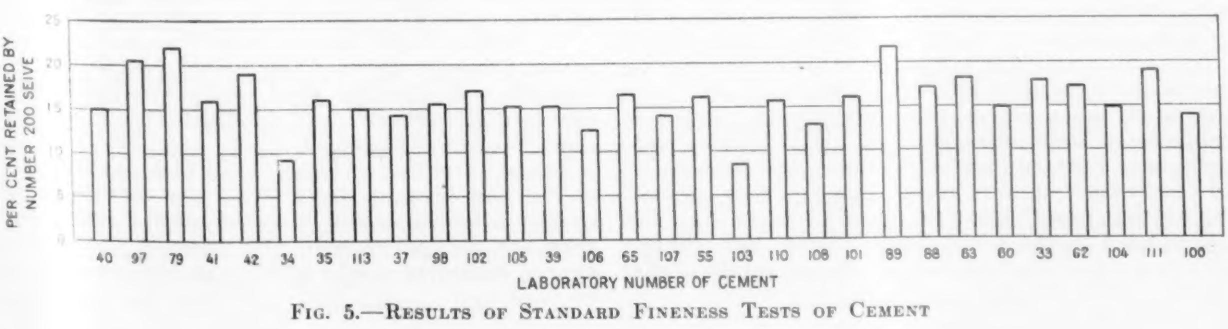


FIG. 5.—RESULTS OF STANDARD FINENESS TESTS OF CEMENT

COMPARISONS AS TO RAW MATERIALS SUGGEST FURTHER INVESTIGATION

With the exception of two Canadian brands, all the cements came from American plants scattered throughout the Central and Western United States, and consequently the raw materials from which these cements were made cover a wide geological range. In attempting to account for differences this thought opens another field for speculation, and after studying the data the impression remains that there does appear to be a tendency for cements from plants closely located, or cements known to be made of similar raw materials, to behave alike. As examples, consider together the following cements: 33, 60, and 63; 34 and 39; 40, 97, and 98; and 62, 110, and 111. This is merely a thought and by itself has small value, but properly developed and considered might in some way not now foreseen help explain basic differences that must exist in these cements that have acted so differently under identical exposure conditions.

BRIQUET TESTS FOR RESISTANCE TO SULPHATE WATER GIVE PROMISING RESULTS

Irrespective of the fundamental causes for the difference of behavior of these cements, there have been decided and consistent differences. It may be that the only possibility for the ultimate solution of this problem is by the chemist, but it is clear that the engineer has immediate need for a satisfactory standard test for cements to be used in concrete to be exposed to the action of sulphate waters, that very poor cements may be eliminated from consideration. With this in mind experiments were conducted to determine an accelerated test, with results in most cases far from satisfactory. It was found, however, that when the standard briquets used in the seven-day test were immediately stored in a 1 per cent solution of sodium sulphate that subsequently their behavior, judged by appearances, seemed to agree surprisingly well with the tests of the cylinders. Briquets of 16 cements were tested after the standard seven-day test under two conditions of exposure. These tests, together with those made on cylinders, make available records on four distinct conditions of exposure as follows:

1. Cylinders without air hardening exposed to a 1 per cent solution of sodium sulphate in the laboratory.
2. Cylinders, after five weeks in air, exposed to the water of Medicine Lake.
3. Briquets broken in the standard seven-day tests exposed to a 1 per cent solution of sodium sulphate in the laboratory.
4. Briquets broken in the standard seven-day tests exposed to a 1 per cent solution of magnesium sulphate in the laboratory.

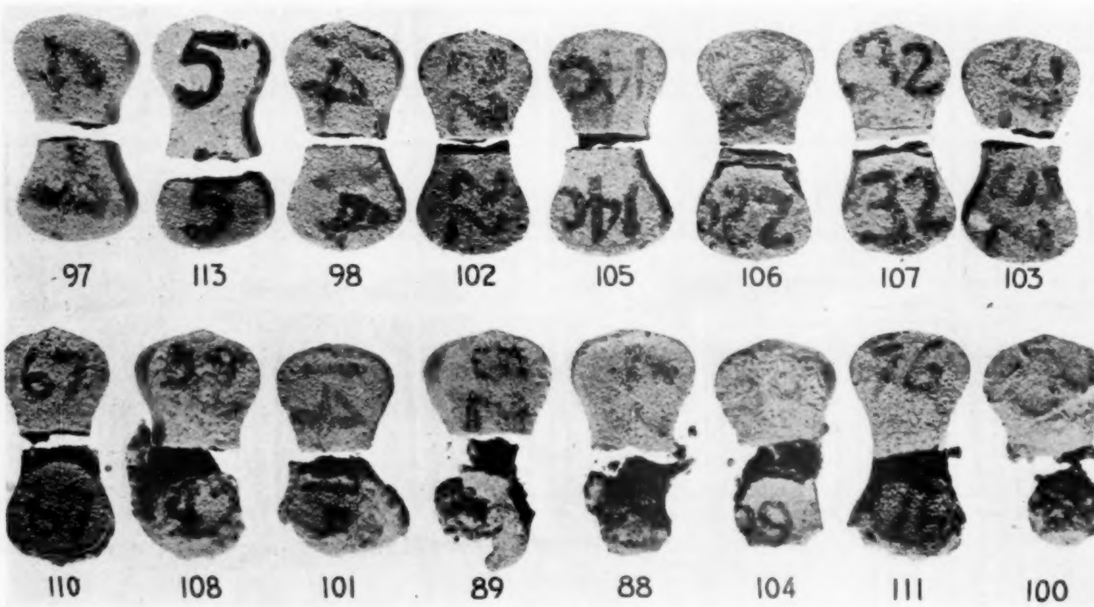


Fig. 6.—Condition of Briquets After Immersion in 1 Per Cent Sulphate Solutions for Six Months. In Each Case the Upper Half of Briquet was Immersed in Magnesium Sulphate Solution and the Lower Half in Sodium Sulphate Solution. Briquets Made with Standard Cement from 16 Different Plants are Shown

Figure 6 shows briquets from the laboratory solutions at six months, in all cases the upper half coming from a 1 per cent magnesium sulphate solution and the lower half from a 1 per cent sodium sulphate solution. It is evident from this illustration that deterioration had progressed much further in the sodium sulphate solution at six months than had action in the magnesium sulphate solution. Considered alone from the standpoint of an accelerated test, immersion in a 1 per cent sodium sulphate solution is the most promising.

In making these briquet tests the quantity of each solution was at no time less than 1 gallon for each 15 briquets and the interval of solution change in no case exceeded four weeks. All solutions were kept at room temperatures of about 72° F.

In the lower half of Figure 7 the ratings at six months of the half briquets from the 1 per cent solutions of sodium sulphate (see fig. 6) on the basis of visual appearance are compared with the strength ratios at one year of cylinders in which the same cements were used.

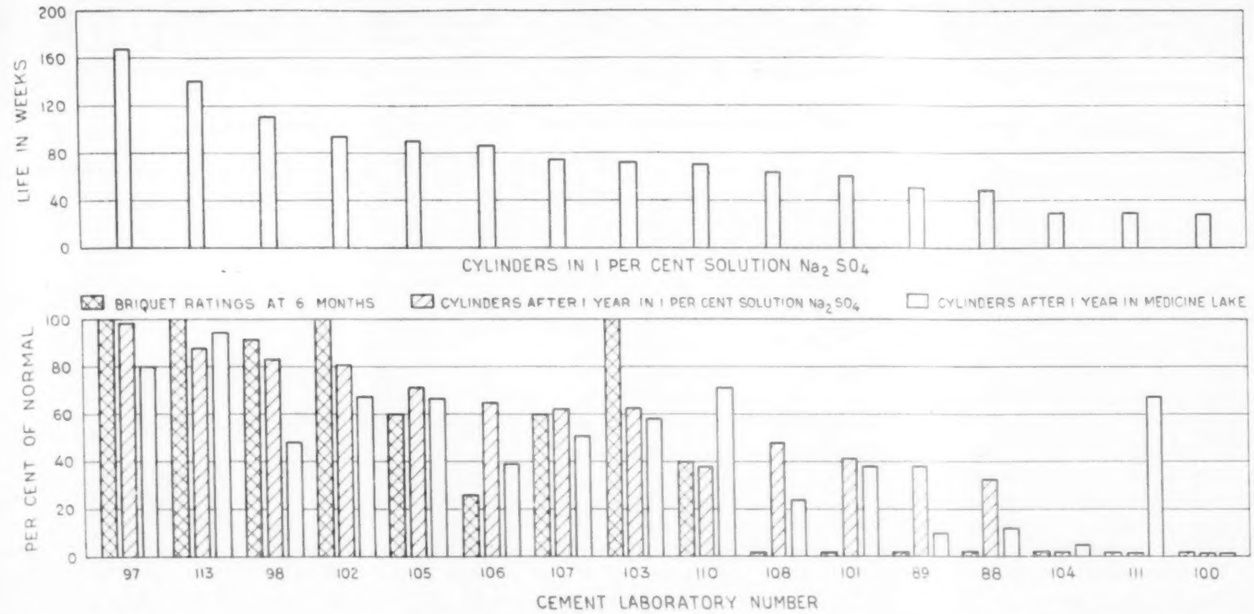


FIG. 7.—RESISTANCE TO THE ACTION OF SULPHATE WATER BY STANDARD PORTLAND CEMENTS FROM 16 PLANTS AS DETERMINED AFTER DIFFERENT CONDITIONS OF EXPOSURE. NOTE THE GENERAL RELIABILITY OF THE BRIQUET RATINGS BY VISUAL INSPECTION AS COMPARED WITH THE CHANGE OF VOLUME AND COMPRESSION TESTS OF THE CYLINDERS

(See Table 4.) Study of Figure 7 justifies the statement that the acceptance or rejection of any of these 16 cements on the basis of the appearance of the briquets at six months would not have been very far wrong, when the action of the cylinders under both exposure conditions is considered. These comparisons are based on tests of specimens made entirely independently of each other without having in mind at the time a correlation of the data. They are in no sense selected tests, as the only reason for choosing the particular 16 cements used is that they were the only Portland cements on which the tests under three conditions of exposure had been made.

These tests lead to the conclusion that a very satisfactory six-month test for resistance to the action of sulphate waters can be made by following substantially the same routine, testing several cements simultaneously in a 1 per cent solution of both sodium and magnesium sulphate and rejecting those giving evidence of more than very slight surface action after six months in either solution.

The feasibility of speeding up this test by increasing the strength of the solution and by using leaner mixes naturally suggests itself. Attempts along this line have been made, and are still under way, without sufficiently consistent results to justify discussion, except to say that there appears to be some possibilities along this line. Until a more accelerated test of at least equal reliability is developed, the one outlined is suggested.

The six-month briquet test has the distinct advantages of reliability, close approximation of severe but not extreme field conditions, and does not require the making of additional and special test pieces. It has the disadvantage of requiring five to six months for completion.

If it may be assumed that the resistance of a cement from any plant is reasonably constant, the time element is not serious, as tests need be made only often enough to make certain that no plant change has brought about a change of resistance. On the other hand, if this assumption is incorrect and the output of a plant varies greatly in resistance, the time required for the test becomes a serious objection. Such evidence as has been collected in the laboratory seems to indicate that the resistance factor of a cement from any given plant is fairly constant. Complete and exact data to support this statement are now lacking, and a series of tests with eight brands of cement, definitely planned to clear up this point, is already well advanced.

With so great a difference in resistance of concrete to the action of sulphate-bearing waters, the first consideration for all concrete to be exposed to such action should be the cement itself, and, regardless of all other precautions, the use of any cement of low resistance, as determined by special tests, should be avoided.

SUMMARY

1. Standard Portland cements from different manufacturing plants may vary greatly in resistance to the action of sulphate waters, as evidenced by laboratory and field tests of 30 Portland cements after exposure periods ranging upward to more than three years. Under the same exposure conditions the more resistant cements have outlived those of least resistance by as much as eight times, while the most resistant 10 have had an average life very nearly four times that of the the 10 of least resistance.

2. Portland cements that have failed quickly in the laboratory in pure solutions of sodium sulphate have ordinarily displayed low resistance in the field to the action of mixed salts.

3. The most desirable Portland cements for concrete exposed to the action of sulphate waters are those that prove most resistant to the action of both pure salts and of mixed salts.

4. Results of standard physical tests of Portland cements give no indication of resistance to sulphate waters.

(Continued on page 92)

DETERMINATION OF PROPORTIONS OF CONSTITUENTS IN CONCRETE

Reported by L. G. CARMICK, Associate Chemist, Division of Tests, U. S. Bureau of Public Roads

THERE are many occasions when it is of considerable importance to know the relative proportions of cement, sand, and stone that were used in the building of some concrete structure. If concrete proves good, we want to know why it is good, and if it is bad our first thought is usually a question as to the proportions used in making it. In practically every laboratory where engineering materials are tested samples of concrete are sent in from time to time and the chemist is asked to determine their proportions. Many of these cases have a legal aspect in that the concrete is suspected of being other than as it should be. Perhaps the contractor is accused of skimping the mix. In such cases a dependable analysis is of the highest importance. At first thought it appears rather a simple matter to make such an analysis, but actually it is very difficult. This is true notwithstanding the fact that considerable work has been done on the problem in a number of good laboratories.

The difficulties involved are of several sorts. In the first place there is apt to be considerable segregation even in well-mixed concrete and a small sample can not be considered as representative of a large mass. When we endeavor to avoid this error by taking a large number of samples we are met by difficulties in the analysis itself and the lack of an entirely satisfactory method. The cement, sand, and stone are all composed of about the same constituents—silica, alumina, and lime, together with some others that are present in lesser amount. The proportions differ in the different materials, and while it is easy enough to tell how much lime the concrete contains it is not easy to say how much of it is from the cement and how much from the sand or stone.

Bulletin 61 of the Iowa State College, Estimation of the Constituents of Portland Cement Concrete, by George W. Burke, offers a method that appeared to be highly promising, and the work reported in this paper has been an effort to determine the degree of accuracy which can be secured with it.

Briefly, the method is as follows: A sample of the concrete, weighing from 1,000 to 1,500 grams, is broken into fragments of not more than 2 inches in size and heated in a muffle furnace for about three hours at a temperature of 600 to 700° C. This causes dehydration of the set cement and should make it easy to separate and clean the coarse aggregate by scraping or brushing. All material below one-quarter inch in size is called "sand-cement mixture." A sample of this is put aside for analysis and from the remainder an effort is made to secure a representative sample of the sand. This is done by sifting and rubbing in a mortar with a rubber-covered pestle. The process is described in detail in the bulletin. The sand-cement and the pure sand thus obtained are each analyzed for silica and for lime. A calculation can then be made of the proportions in the sand-cement mixture with either of these data and assuming the percentage of lime or silica in the cement.

For example, representing the proportional weight of the cement present by C and the proportional weight of the sand by S, a unit weight of the mixture can be expressed by

$$C+S=1 \qquad (1)$$

Knowing the lime content of the cement, sand, and sand-cement mixture we can write

$$P_cC+P_sS=P_m\,(C+S) \qquad (2)$$

in which P_c = per cent CaO in the cement,

P_s = per cent CaO in the sand,
P_m = per cent CaO in the sand-cement mixture.

Solving equations 1 and 2 simultaneously, the values of C and S may be calculated. In the same way calculations may be made on the basis of the silica content of the materials. In using this method when a sample of the original cement is not available it is necessary to assume an analysis for it. Twenty-one per cent silica and 62 per cent lime are considered as about average.

Preliminary experiments, made by the Bureau of Public Roads but not given in detail here, have shown that when the coarse aggregate is limestone or dolomite the results obtained by this method are very uncertain. Baking the sample at 600° to 700° C. partially calcines most limestones, and if a lower temperature is used it is hard to disintegrate the concrete. Many small fragments of the limestone are sure to be included with the sand-cement mixture and seriously impair the accuracy of the results. Some other stones, such as granites which are not thoroughly sound, are easily broken down after heating.

To obtain even approximately correct results by this method it appears to be necessary that the coarse aggregate be a rock that is not much affected by the heat used, not easily crumbled, and noncalcareous, and also that the sand be noncalcareous and not much affected by dilute hydrochloric acid.

As a test of the method, 10 small cylinders were made of a mortar consisting of 1 part cement and 2½ parts Potomac sand which meets the above conditions. These cylinders were analyzed and the results are given in Table 1. The first three cylinders were treated exactly in accordance with Burke's dry method. All of the sand from cylinders Nos. 4, 5, 6, and 7 were washed with a 5 per cent solution of hydrochloric acid and the sands from cylinders Nos. 8, 9, and 10 were washed with water. It seems evident that it is necessary to wash the sand with acid, as otherwise it carries with it a considerable amount of cement. It is apparent also that a much greater degree of accuracy is obtained by using the true lime content of the cement (59.60 per cent) instead of an assumed value of 62 per cent. Calculations made on the basis of the silica content were so wide of the mark that they are not given.

Believing it possible to improve on the above results by greater care and attention to detail, another set of 12 cylinders was made from the same cement and sand, using a 1 to 2 mix.

TABLE 1.—*Test results of analysis of cylinders made with 1 part cement and 2.5 parts Potomac sand*

ANALYSIS OF MATERIALS

Per cent	Sand	Cement	Sand and cement mix (theoretical)
SiO_2	89.90	20.80	70.16
CaO	.50	59.60	17.39

ANALYSIS OF MORTAR CYLINDERS

Cylinder No.	Sand and cement		Sand		Cement to sand, parts		Remarks
	SiO_2	CaO*	SiO_2	CaO	Based on true lime content of cement	Lime content of cement assumed as 62 per cent	
	Per cent	*Per cent*	*Per cent*	*Per cent*			
1	70.44	16.23	91.38	1.54	1 : 2.95	1 : 3.11	Sand brushed dry.
2	70.75	16.55	87.80	3.34	1 : 3.25	1 : 3.42	
3	70.40	17.22	88.58	2.74	1 : 2.92	1 : 3.10	
4	70.73	16.69	95.14	.30	1 : 2.60	1 : 2.76	Sand washed with dilute HCl (5 per cent).
5	71.83	15.90	94.73	.13	1 : 2.77	1 : 2.92	
6	70.31	16.85	94.55	.24	1 : 2.57	1 : 2.71	
7	70.21	17.06	94.00	.34	1 : 2.53	1 : 2.69	
8	70.87	16.41	90.17	2.50	1 : 3.10	1 : 3.27	Sand washed with water.
9	71.40	16.13	92.18	1.97	1 : 3.06	1 : 3.23	
10	71.17	16.40	91.20	2.22	1 : 3.05	1 : 3.22	

The sands from the first four were brushed dry, those from the next four were washed with a 5 per cent hydrochloric acid solution, and those from the last four were washed with water. The greatest care was taken in the preparation of the samples and in the analyses. The results are given in Table 2 and show a considerable improvement in accuracy. It was again apparent that it is necessary to wash the sand with acid and to know the true lime content of the cement. This series also showed that the silica content is far less reliable as a basis for calculations.

TABLE 2.—*Test results of analysis of cylinders made with 1 part cement and 2 parts Potomac sand*

ANALYSIS OF MATERIALS

Per cent	Sand	Cement	Sand and cement mix (theoretical)
SiO_2	89.90	20.80	66.87
CaO	.50	59.60	20.29

ANALYSIS OF MORTAR CYLINDERS

Cylinder No.	Sand and cement		Sand		Cement to sand, parts		Remarks
	SiO_2	CaO	SiO_2	CaO	Based on true lime content of cement	Lime content of cement assumed as 62 per cent	
	Per cent	*Per cent*	*Per cent*	*Per cent*			
1	67.15	20.00	88.40	1.45	1 : 2.13	1 : 2.26	Sand brushed dry.
2	67.25	19.80	88.70	1.65	1 : 2.19	1 : 2.32	
3	67.20	19.85	89.00	1.55	1 : 2.17	1 : 2.30	
4	66.50	20.40	88.65	1.50	1 : 2.07	1 : 2.20	
5	66.95	20.10	93.25	.30	1 : 2.00	1 : 2.11	Sand washed with dilute HCl (5 per cent).
6	66.45	20.45	93.10	.20	1 : 1.93	1 : 2.03	
7	67.15	19.95	92.85	.25	1 : 2.01	1 : 2.13	
8	67.10	19.85	93.20	.20	1 : 2.02	1 : 2.15	
9	66.90	20.20	88.15	1.40	1 : 2.10	1 : 2.22	Sand washed with water.
10	67.00	20.25	88.65	1.45	1 : 2.09	1 : 2.22	
11	67.00	20.35	89.10	1.35	1 : 2.07	1 : 2.19	
12	66.55	20.05	88.55	1.50	1 : 2.13	1 : 2.26	

It is believed that this second series shows the maximum degree of accuracy that can be hoped for in the case of mortars when the conditions and materials are almost ideal.

Continuing the investigation, 10 concrete cylinders were cast, using the same sand but a different cement, and a 1:2:4 mix. The coarse aggregate consisted of clean siliceous pebbles 1 inch or less in size. The test results are given in Table 3. Again a great improvement is noted in those cases where acid washing was resorted to.

TABLE 3.—*Test results of analysis of cylinders made with 1 part cement, 2 parts Potomac sand and 4 parts gravel*

ANALYSIS OF MATERIALS

Per cent	Sand	Cement	Sand and cement (theoretical)
SiO_2	89.90	21.15	66.98
CaO	.50	61.10	20.70

ANALYSIS OF CYLINDERS

Cylinder No.	Weight of sample (grams)	Weight of stone (grams)	Weight of sand (grams)	Weight of cement (grams)	Sand and cement		Sand		Proportions found	Remarks
					SiO_2	CaO	SiO_2	CaO		
					Per ct	*Per ct*	*Per ct*	*Per ct*		
1	1,040	575	321	144	67.20	20.15	90.90	1.85	1:2.23:4.00	Sand brushed dry.
2	1,115	660	319	136	66.15	19.85	91.45	2.15	1:2.34:4.85	
3	1,260	740	366	154	65.70	19.75	88.70	2.30	1:2.37:4.80	
4	1,075	635	295	145	65.95	20.40	93.15	.35	1:2.03:4.38	Sand washed with HCl (5 per cent).
5	1,210	680	357	173	68.05	20.10	92.75	.20	1:2.06:3.93	
6	1,315	760	367	188	67.75	20.75	93.25	.20	1:1.95:4.04	
7	1,175	635	355	185	66.45	21.05	93.40	.15	1:1.90:3.43	
8	1,225	735	333	157	67.10	21.10	90.85	2.20	1:2.12:4.68	Sand washed with water.
9	1,085	610	333	142	66.25	19.60	89.10	1.85	1:2.34:4.30	
10	1,145	640	346	159	66.00	20.35	90.15	1.70	1:2.17:4.02	

The following conclusions are drawn from these experiments:

(1) It is of the utmost importance to have samples of the original constituent materials used in making the concrete. It is particularly necessary to know the true CaO content of the cement, as actual variation from an assumed value may introduce a considerable error.

(2) Calculations should be made on the basis of the CaO content of the cement. Those made on the basis of silica content are not at all reliable.

(3) Reasonable accuracy can not be secured unless the fine aggregate is siliceous and little affected by dilute hydrochloric acid, and the coarse aggregate a noncalcareous rock which will not be broken down by the necessary heating.

(4) Washing the whole of the sand with dilute hydrochloric acid secures greatly increased accuracy.

(5) The best results which can be obtained by this method are only approximate, since—

(*a*) Results having a high degree of accuracy can not always be obtained by the analyses of samples of known composition; and,

(*b*) Small samples of concrete such as would be used in this method may not be truly representative of the mass from which they were taken.

(6) The limitations which have been pointed out and the lack of accuracy under highly favorably conditions show that this method is of practical value only when approximate rather than exact information is desired.

A NEW MOIST-CLOSET AND STORAGE TANK APPARATUS

Reported by D. O. Woolf, Junior Materials Engineer, Division of Tests, U. S. Bureau of Public Roads

THE Division of Tests of the Bureau of Public Roads has recently completed the installation of a new moist-closet and storage-tank apparatus for cement test specimens. This equipment was designed, constructed, and erected by the division personnel and replaces a wood frame apparatus which had been in use for a number of years.

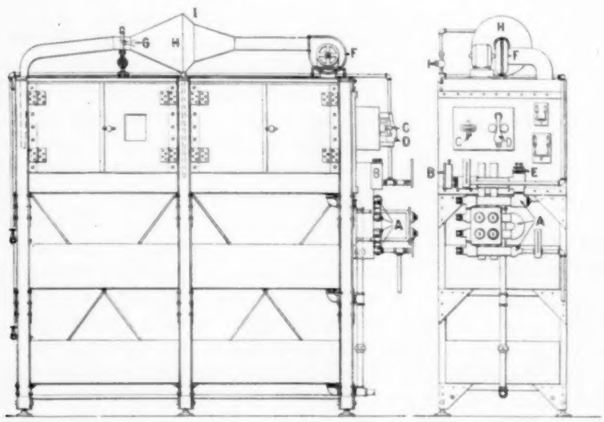


FIG. 1.—MOIST CLOSET AND STORAGE TANKS WITH HUMIDIFYING AND TEMPERATURE CONTROL APPARATUS

Testing engineers have long appreciated the necessity of controlling to a greater degree the humidity and temperature of the air in which neat cement pats and mortar specimens are stored for the first 24 hours. In addition to this, it is known that the temperature of storage water has a considerable effect on the strength of the mortar, and should be kept between certain definite limits to obtain comparable results from tests made at different times. As a result of consideration of these effects, the following requirement has recently been added by the American Society for Testing Materials to their standard methods for testing Portland cement:

> The temperature of the room, the materials, the mixing water, the moist closet and storage-tank water shall be maintained as nearly as practicable at 21° C. (70° F.), and the mixing water, moist closet, and the water in the storage tank shall not vary from this temperature more than 3° C. (5° F.).[1]

In the design of this apparatus an effort was made to obtain the following:

1. Structural soundness.
2. Control of temperature of the moist closet air and storage water.
3. A high percentage of humidity in the moist closet and means for obtaining this humidity quickly.
4. A system of control of temperature and humidity which could easily be applied to moist-closet and storage-tank apparatus.

The tanks and moist closet shown in Figure 1 are made of soapstone and supported by a steel frame.

[1] A. S. T. M. Standard Method, serial designation C 9-26.

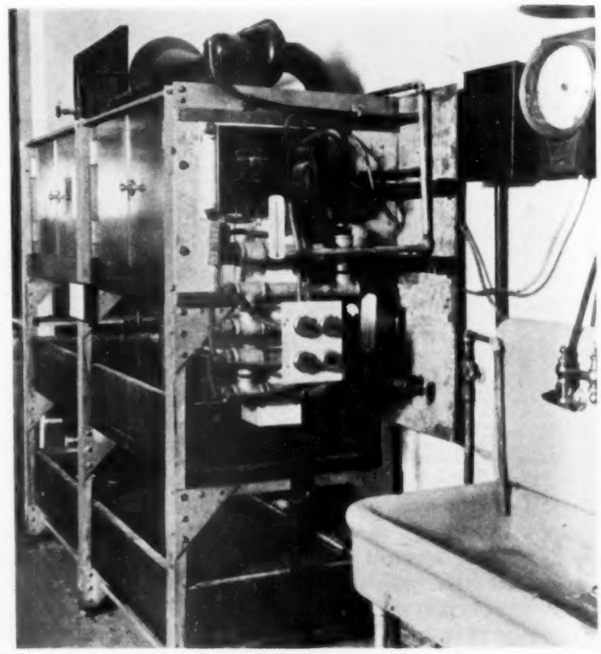


FIG. 2.—GENERAL VIEW OF CLOSET AND STORAGE TANKS

Three-inch channels were used as the main members of the frame and the assembly was joined and stiffened with gusset plates and tension rods. The completed apparatus is thoroughly rigid and shows no structural weakness. Leveling screws were necessary on each foot because of the unevenness of the laboratory floor. Figure 2 shows a view of the complete installation.

Each of the two storage tanks has an 8-inch depth of water and has sufficient space for about 1,650 briquetes or 1,300 2-inch cubes. The moist closet has three shelves for briquetes or cubes. If necessary, the two upper shelves can be removed and tall specimens cured in the cabinet.

There are three features of special interest in this apparatus. One is the electrical apparatus for heating and controlling the temperature of the water used to cure the test specimens. The heating is done by four helical coil immersion water heaters which are mounted in a pipe coil (fig. 1, A) at the right end of the structure. The heated water then passes through a fifth section of the coil which contains an electric immersion thermostat (fig. 1, B) for controlling the temperature of the water. Expansion or contraction of a glass rod in this instrument actuates a pony relay (fig. 1, C), which in turn opens or closes a magnetic switch (fig. 1, D), through which current to one or more of the heating units may be carried. The temperature of the supply water may be regulated by control of the number of heating units in operation, by adjustment of the thermostat, or by regulation of the quantity of the water flowing.

It is the present practice to adjust the valves in the water line to deliver the desired flow of water and then to turn on the number of heating units necessary to furnish a water temperature just under that which is desired. The temperature is then raised and held to the desired degree by the heating element controlled by the thermostat. With an appreciable change in the temperature of the water supply it is necessary to regulate the thermostat accordingly.

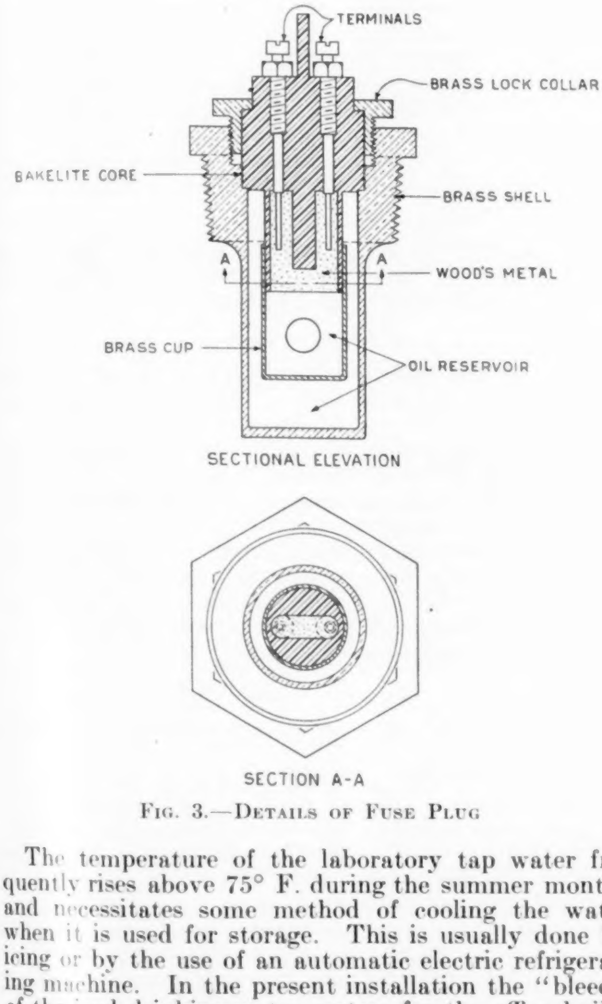


FIG. 3.—DETAILS OF FUSE PLUG

The temperature of the laboratory tap water frequently rises above 75° F. during the summer months and necessitates some method of cooling the water when it is used for storage. This is usually done by icing or by the use of an automatic electric refrigerating machine. In the present installation the "bleed" of the iced drinking-water system for the office building is used to supply the water for the moist closet and storage tanks. The water is delivered to the heating coils at a temperature of about 50° F. and is heated to the desired temperature. It is possible that the most satisfactory results could be obtained by the use of a refrigerating machine, but with cold water available from the drinking system the cost of the former was considered not justified.

The second feature of interest is the fuse plug (fig. 1, E) which protects the heating coils against burning out. In the past the coils have burnt out by overheating resulting from stoppage of the valves or pipe line with sediment or from the water supply being shut off without the knowledge of the laboratory personnel. When either happens the water in the pipe coils quickly reaches the boiling point and the heating element is destroyed. To prevent this, the

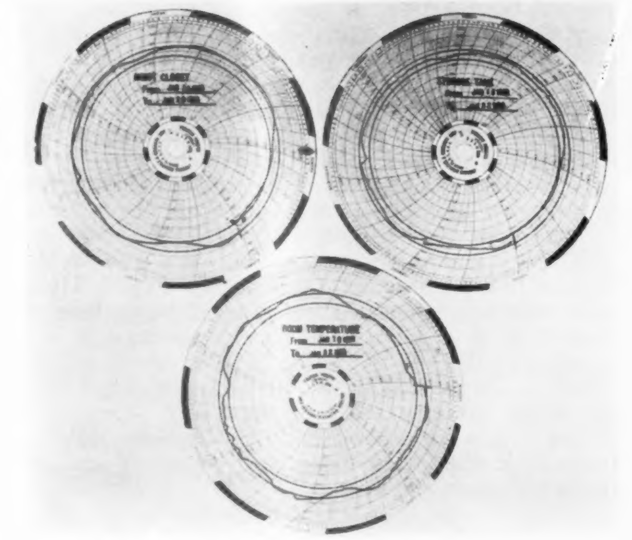


FIG. 4.—TYPICAL TEMPERATURE RECORDS

fuse plug is inserted in the pipe coil just beyond the last heating element. This plug, shown in Figure 3, is inserted in one side of the line from the main switch to the heating coils. It consists of a brass shell, threaded to screw in a 2-inch standard tee, a bakelite center core, and a brass lock collar which holds the bakelite core in position. Brass terminals are mounted in the bakelite core and project into the interior opening. Contact is made between the two terminals by Wood's metal, an alloy of bismuth, lead, tin, and cadmium, which melts at about 60½° C.

Should the temperature of the water in the pipe coil rise to this point, the Wood's metal will melt and break the contact between the terminals, thus opening the heating-coil circuit. This is similar to the device used in some electric coffee percolators. The molten Wood's metal is caught by a brass cup and may be used again to close the circuit. To permit better transfer of heat from the outside water to the alloy and also to preclude the formation of an arc across the terminals, the interior of the plug is filled with a light lubricating oil.

The third feature of interest is the apparatus for raising the humidity of the air in the moist closet quickly. This consists of a centrifugal blower (fig. 1, F.) which draws air from the moist closet, forces it through a conical spray of water, and returns it to the moist closet. The apparatus is mounted on top of the moist closet. The water is discharged by the spray nozzle (fig. 1, G) into a mixing cone (fig. 1, H), where it hits a section (fig. 1, I) of the cone at an angle of about 45°, is deflected at right angles to its original path, and meets the stream coming from the other side of the cone. This produces a mist which is picked up by the air stream and is carried into the moist closet.

The spray and blower are run only during working hours when the moist-closet doors are being opened to insert specimens. During the night 2 inches of water in the bottom of the cabinet are depended upon to keep the humidity up to the desired degree.

Several types of spray nozzles have been experimented with but none of them have given entirely satisfactory results. The humidity in the cabinet has,

however, been kept at a very high degree the average being about 95, and when the spray and blower are working, 97. Further experimentation with the spray nozzle is desirable and will be conducted as time permits. The humidity is measured by a wet-and-dry-bulb hygrometer mounted inside the moist closet and viewed through a window in the door.

The temperatures of the moist closet, storage tank, and room air adjacent to the apparatus are registered by recording thermometers. Owing to the open tanks, the room air temperature has a considerable effect on the temperature of the storage water. During severe weather, when the room air temperature will probably drop to 45° or 50° F., the thermostat is set to a slightly higher value at close of work. Figure 4 shows a normal set of temperature records for the moist closet, storage tank, and room air.

Construction drawings for the moist-closet and storage-tank apparatus have been prepared and may be obtained upon request.

HIGHWAY TRANSPORTATION AN IMPORTANT FACTOR IN MARKETING FRUITS AND VEGETABLES [1]

The larger cities receive such a great proportion of the total carload shipments of fresh fruits and vegetables that it might seem at first glance that the rest of the country is rather poorly supplied. In 1926, for example, 36 of our principal cities unloaded 58 per cent of the car-lot shipments of 16 leading fruits and vegetables. Nevertheless, the distribution of fruits and vegetables throughout the country is more thorough than these figures would indicate. The explanation is largely the motor truck.

As a matter of fact, in certain eastern areas for which information is available the smaller markets appear to be well served with fruits and vegetables. An average of from 40 to 45 per cent of the carload receipts of box apples in 17 southern cities in 1926 were shipped out again to the surrounding territory by auto truck or in less than carload shipments.

In general, the machinery for the redistribution of shipped-in fruits and vegetables to the small cities and to the rural population is fairly efficient, and the auto truck is constantly improving it. In Pennsylvania from 10 to 50 per cent of the southern peaches used in 1926 in a number of cities with population ranging from 20,000 to 50,000 were brought in by truck or in less than car-lot shipments from Philadelphia or Baltimore. Southern peaches are on sale in most of the small towns and villages of eastern Pennsylvania during the heavy shipping season. Many dealers in the smaller cities have their own trucks and make regular trips to the larger markets for supplies. Peddlers and hucksters also assist in the distribution.

It has been contended, from the fact that car-lot shipments go principally to the larger markets, that more car-lot shipments might profitably go to the smaller markets, many of which have cold-storage plants. This may be rather difficult with the more perishable products and those subject to sharp price fluctuations. In small markets it may take a dealer several days to dispose of a carload. Meantime, falling prices in the larger markets may enable competitors to bring in supplies by truck or in less than carload lots at prices which the car-lot receiver can not meet without heavy loss. Lower transportation charges on car-lot shipments to small markets may be offset by the greater risk. By using the motor truck, the dealer in the small city often feels he has a better choice of fresh produce and can be assured of better value in buying it.

Much progress has been made in enlarging the demand for fruits and vegetables by effecting a wider and more thorough distribution among the consuming population. Dealers using their own or hired trucks, and hucksters and peddlers who handle locally grown as well as shipped-in produce, have widened the area and increased the intensiveness of distribution. Their task has been made easier by the general development of the fruit and vegetable industry, which has improved the quality of produce offered, lessened waste, and made perishables available throughout a longer season.

[1] Reprinted from The Official Record of the U. S. Department of Agriculture.

RESISTANCE OF PORTLAND CEMENT CONCRETE TO THE ACTION OF SULPHATE WATERS AS INFLUENCED BY THE CEMENT

(Continued from page 87)

5. Results of standard chemical analyses of Portland cements give no indication of resistance to sulphate waters.

6. The geological differences of the raw materials of different cements may possibly be one factor that must be considered in attempting to account for differences in resistance to sulphate waters.

7. A satisfactory accelerated test is needed to facilitate determining the resistance of a Portland cement to the action of sulphate waters. Until a better test is developed, the six-months' briquet test, as outlined in this paper, is suggested.

NEW BULLETIN ON HIGHWAY BRIDGE SURVEYS

Highway Bridge Surveys, by C. B. McCullough, bridge engineer, Oregon Highway Commission, has recently been issued by the United States Department of Agriculture as Technical Bulletin No. 55. This bulletin discusses methods of reporting survey data, scope of surveys, investigations as to materials available, waterway required, stream gradients, foundation conditions, traffic, and the preparation of sketches, maps, and profiles. The bulletin has been prepared for the purpose of furnishing detailed instructions to field engineers as to the data necessary in designing highway bridges.

REPORT ON THE SOILS OF CUBA

Investigators studying the relation of soils to highway design and interested in methods of soil study and classification for agricultural purposes will find much useful information in The Soils of Cuba, by Hugh H. Bennett and Robert V. Allison, published by the Tropical Plant Research Foundation of Washington, D. C. The publication is the result of cooperative study by the Tropical Plant Research Foundation and the Bureau of Soils of the United States Department of Agriculture. A short discussion of the characteristics of the types of soil encountered from the point of view of the highway engineer is presented.

ROAD PUBLICATIONS OF BUREAU OF PUBLIC ROADS

Applicants are urgently requested to ask only for those publications in which they are particularly interested. The Department can not undertake to supply complete sets nor to send free more than one copy of any publication to any one person. The editions of some of the publications are necessarily limited, and when the Department's free supply is exhausted and no funds are available for procuring additional copies, applicants are referred to the Superintendent of Documents, Government Printing Office, this city, who has them for sale at a nominal price, under the law of January 12, 1895. Those publications in this list, the Department supply of which is exhausted, can only be secured by purchase from the Superintendent of Documents, who is not authorized to furnish publications free.

ANNUAL REPORTS

Report of the Chief of the Bureau of Public Roads, 1924.
Report of the Chief of the Bureau of Public Roads, 1925.
Report of the Chief of the Bureau of Public Roads, 1927.

DEPARTMENT BULLETINS

No. 105D. Progress Report of Experiments in Dust Prevention and Road Preservation, 1913.
*136D. Highway Bonds. 20c.
220D. Road Models.
257D. Progress Report of Experiments in Dust Prevention and Road Preservation, 1914.
*314D. Methods for the Examination of Bituminous Road Materials. 10c.
*347D. Methods for the Determination of the Physical Properties of Road-Building Rock. 10c.
*370D. The Results of Physical Tests of Road-Building Rock. 15c.
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387D. Public Road Mileage and Revenues in the Southern States, 1914.
388D. Public Road Mileage and Revenues in the New England States, 1914.
390D. Public Road Mileage and Revenues in the United States, 1914. A Summary.
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*1077D. Portland Cement Concrete Roads. 15c.
1259D. Standard Specifications for Steel Highway Bridges, adopted by the American Association of State Highway Officials and approved by the Secretary of Agriculture for use in connection with Federal-aid road work.
1279D. Rural Highway Mileage, Income, and Expenditures, 1921 and 1922.

DEPARTMENT BULLETINS—Continued

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DEPARTMENT CIRCULARS

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331C. Standard Specifications for Corrugated Metal Pipe Culverts.

TECHNICAL BULLETIN

No. 55. Highway Bridge Surveys.

MISCELLANEOUS CIRCULARS

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914Y. Highways and Highway Transportation.
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TRANSPORTATION SURVEY REPORTS

Report of a Survey of Transportation on the State Highway System of Connecticut.
Report of a Survey of Transportation on the State Highway System of Ohio.
Report of a Survey of Transportation on the State Highways of Vermont.
Report of a Survey of Transportation on the State Highways of New Hampshire.

REPRINTS FROM THE JOURNAL OF AGRICULTURAL RESEARCH

Vol. 5, No. 17, D- 2. Effect of Controllable Variables upon the Penetration Test for Asphalts and Asphalt Cements.
Vol. 5, No. 19, D- 3. Relation Between Properties of Hardness and Toughness of Road-Building Rock.
Vol. 5, No. 24, D- 6. A New Penetration Needle for Use in Testing Bituminous Materials.
Vol. 6, No. 6, D- 8. Tests of Three Large-Sized Reinforced-Concrete Slabs Under Concentrated Loading.
Vol. 11, No. 10, D-15. Tests of a Large-Sized Reinforced-Concrete Slab Subjected to Eccentric Concentrated Loads.

* Department supply exhausted.